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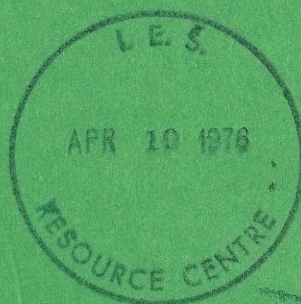
Report EPS 3-AP-75-4

COMBUSTION TECHNOLOGY FOR THE DISPOSAL AND UTILIZATION
OF WOOD RESIDUE, 1975.

CA 1 EP53075E04



Combustion Technology for the Disposal and Utilization of Wood Residue



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Economic and Technical Review
Report EPS 3-AP-75-4

Air Pollution
Control Directorate
October 1975

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**COMBUSTION TECHNOLOGY FOR THE DISPOSAL AND
UTILIZATION OF WOOD RESIDUE***

Combustion Sources Division

Abatement and Compliance Branch

Air Pollution Control Directorate

Report EPS 3-AP-75-4

May 1975

*The report is based on a study undertaken for the Department of the Environment by B. H. Levelton and Associates Limited, Vancouver, under Contract No. SS03 KE 204-3-EPS 45.

REVIEW NOTICE

This report has been reviewed by the Air Pollution Control Directorate, Environmental Protection Service, and approved for publication. Approval does not necessarily reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

ABSTRACT

This report provides a state-of-the-art review of new and emerging technology for the utilization and disposal of wood residues with emphasis on air pollution potential and cost. Disposal by thermal decomposition is emphasized and utilization is limited to useful energy aspects.

RÉSUMÉ

Ce rapport fait une mise à jour de la technologie nouvelle, ou sur le point d'apparaître, de l'utilisation et de l'élimination des résidus du bois en mettant l'accent sur les possibilités de pollution de l'air et sur les coûts. On parle surtout de l'élimination par décomposition thermique et l'utilisation n'est traitée que du point de vue des aspects énergétiques utiles.

TABLE OF CONTENTS

	PAGE
ABSTRACT	i
RÉSUMÉ	ii
LIST OF TABLES	vi
LIST OF FIGURES	viii
1 INTRODUCTION	1
1.1 Scope	1
1.2 Purpose	1
2 INDUSTRY DESCRIPTION	2
2.1 General	2
2.2 Total Production	2
2.3 Predictions for Future Production	6
3 ENERGY AND FUEL REQUIREMENTS OF THE FOREST INDUSTRY	6
3.1 Total Requirements, 1970	6
3.2 Trends by Area of Province	6
3.3 Projection of Fuel and Energy Requirements to 2002	7
4 SOURCES OF ENERGY	8
4.1 Fuel Oil	8
4.2 Natural Gas	13
4.3 Coal	13
4.4 Wood	14
5 WOOD RESIDUES AS AN ENERGY SOURCE	16
5.1 Background	16
5.2 Quality of Wood Residues	16
5.3 Distribution of Wood Residue Production	16
5.4 Volumes of Wood Residues in British Columbia	20
5.5 Utilization of Wood Residues	20
5.6 Value of Wood Residue Utilization	24
5.7 Energy Requirements for a Sawmill	24

5.8	The Economics of Central Steam and Power Generation	25
6	TRANSPORTATION COSTS	25
7	UTILIZATION AND DISPOSAL OF WOOD RESIDUES	26
7.1	General	26
7.2	Land Disposal	26
7.3	Thermal Decomposition	27
7.4	Products	35
8	THERMAL DECOMPOSITION SYSTEMS FOR ON-SITE DISPOSAL OF WOOD RESIDUES	38
8.1	General	38
8.2	Modified Conical Incinerators	38
8.3	Pit Incinerators	43
8.4	Multiple Chamber Incinerators	48
8.5	Cyclone Suspension Burners	54
8.6	Integral Cyclone Suspension Burner-Combustion Chamber Packaged Unit	58
8.7	Fluidized Bed Combustors	63
8.8	Gasification Systems	67
8.9	Fluid Bed Charcoal Reactor	72
8.10	Applications Summary	76
9	RESEARCH AND DEVELOPMENT	76
9.1	General	76
9.2	Conical Incinerator	76
9.3	Pit Incinerator	76
9.4	Inventive On-Site Application for Clean Hot Gases	76
9.5	Regional Energy Recovery Plants	80
9.6	Fuel Gas from Gasification of Wood	80
9.7	Production of Fuel-Grade Methanol	81

10	CONCLUSIONS	83
10.1	General	83
10.2	Technology	84
10.3	Product Development	85
10.4	Regional Energy Recovery	85
10.5	Required Research	85
	REFERENCES	87
APPENDIX	TERMINOLOGY AND CONVERSION UNITS	89

LIST OF TABLES

TABLE		PAGE
1	BRITISH COLUMBIA TOTAL LUMBER PRODUCTION, 1950-1972	3
2	DISTRIBUTION OF PULP AND PAPER PRODUCTION CAPACITY IN BRITISH COLUMBIA, 1972	5
3	BRITISH COLUMBIA PULP AND PAPER PRODUCTION, 1960-1972	5
4	PROJECTIONS TO 1992 FOR BRITISH COLUMBIA FOREST INDUSTRY PRODUCTION	7
5	FUEL AND ENERGY REQUIREMENTS AND PRODUCTION IN BRITISH COLUMBIA SAWMILLS AND PLANING MILLS, 1970	8
6	FUEL AND ENERGY CONSUMPTION IN THE BRITISH COLUMBIA FOREST INDUSTRY, 1970	9
7	PROJECTION OF FUEL AND ENERGY REQUIREMENTS IN THE BRITISH COLUMBIA FOREST INDUSTRY	10
8	SOME TYPICAL FUEL AND ENERGY PURCHASE COSTS IN BRITISH COLUMBIA, 1972	11
9	FUEL COST COMPARISON OF SOME INDUSTRIAL FUELS IN BRITISH COLUMBIA, AUGUST 1974	12
10	BOILER FUEL COST COMPARISON, 1970	15
11	WOOD RESIDUE PRODUCTION FROM SAWMILLS IN BRITISH COLUMBIA	19
12	TOTAL WOOD RESIDUES IN BRITISH COLUMBIA FROM SAWMILLING AND PLYWOOD OPERATIONS, 1969	21
13	HOG FUEL STUDY FOR LOWER COAST OF BRITISH COLUMBIA, 1972	21
14	TYPICAL METHODS OF WOOD RESIDUE DISPOSAL IN BRITISH COLUMBIA	22
15	EXISTING AND PROJECTED UTILIZATION OF WOOD RESIDUE IN BRITISH COLUMBIA	23
16	EFFICIENCY OF PARTICULATE MATTER REMOVAL TECHNIQUES	35

17	BASE COSTS FOR 'BURN-O-MATIC' INCINERATOR , JULY 1974	42
18	COSTS OF VARIOUS PIT INCINERATORS MADE BY CONSUMAT SYSTEMS INCORPORATED	47
19	PARTICULATE EMISSIONS FROM MULTIPLE CHAMBER INCINERATORS	53
20	PRICES FOR ENERGEX CYCLONE SUSPENSION BURNERS , JULY 1974	56
21	APPLICATIONS SUMMARY	77
22	COST SUMMARY, DOLLARS , SEPTEMBER 1974	78
23	COMBUSTION ENERGY DENSITY OF FUELS	82
24	RELATIVE COSTS OF FUEL	82

LIST OF FIGURES

FIGURE		PAGE
1	SOFTWOOD LUMBER PRODUCTION, CANADA, 1951-2001	4
2	SOFTWOOD PLYWOOD PRODUCTION, CANADA, 1951-2001	4
3	DISTRIBUTION OF WOOD RESIDUE PRODUCTION IN BRITISH COLUMBIA	18
4	BOILER WITH A DUTCH OVEN FURNACE	29
5	INCLINED WATER-COOLED GRATE BOILER (FOSTER WHEELER, LIMITED)	30
6	CYCLONE SUSPENSION BURNER (ENERGEX, LIMITED)	31
7	MODIFIED CONICAL INCINERATOR (LAMB-CARGATE)	39
8	MODIFIED CONICAL INCINERATOR	40
9	OPEN PIT INCINERATOR (PLIBRICO CANADA, LIMITED)	44
10	PORTABLE AIR CURTAIN SUPPLY FOR PIT INCINERATORS UP TO 56 FEET LONG	45
11	CAMRAN AIR CURTAIN COMBUSTOR	49
12	TYPICAL CROSS SECTION AND FLOW OF A MODEL '60' AUTOMATED COMBUSTION FURNACE FIRING A BOILER	50
13	'PILE BURNING' TYPE MULTIPLE CHAMBER INCINERATOR	51
14	CYCLONE SUSPENSION BURNER SYSTEM (ENERGEX, LIMITED)	55
15	'CYCLOTUBE' CYCLONE SUSPENSION BURNER (ENERGEX, LIMITED)	55
16	CYCLONE SUSPENSION BURNER WITH COMBUSTION CHAMBER SYSTEM (WAYCOTT INDUSTRIES, LIMITED)	59
17	'TURBULATOR' CYCLONE SUSPENSION BURNER WITH INTEGRAL COMBUSTION CHAMBER (WAYCOTT INDUSTRIES, LIMITED)	60

18	CYCLONE SUSPENSION BURNER-COMBUSTION CHAMBER, INTEGRAL PACKAGED UNIT (WAYCOTT INDUSTRIES, LIMITED)	61
19	FLUIDIZED BED COMBUSTOR SYSTEM (ENVIRONMENTAL PRODUCTS, INCORPORATED)	64
20	'FLUID FLAME' FLUIDIZED BED COMBUSTOR (ENVIRONMENTAL PRODUCTS, INCORPORATED)	65
21	WOOD GASIFICATION SYSTEM (MOORE CANADA, LIMITED)	68
22	1/10 SCALE GASIFICATION PILOT PLANT CONVERTING WOOD TO COMBUSTIBLE GAS (MOORE CANADA, LIMITED)	69
23	FLUIDIZED BED WOOD CHARCOAL REACTOR SYSTEM	74
24	'THERMEX' FLUIDIZED BED REACTOR (ALBERTA INDUSTRIAL DEVELOPMENT, LIMITED)	75

1 INTRODUCTION

1.1 Scope

The problem of wood residue disposal is extensive and methods for utilization and disposal are numerous; consequently, the scope of this report has been limited to:

- (a) Consideration of only those wood residues generated at the site of a wood processing facility. This excludes residues of forest operations but includes slashings, etc., that would arrive at a wood processing facility. Pulp and paper operations are included because many integrated sawmills and pulp facilities exist. Generally the wood residues considered will not be suitable as marketable products.
- (b) Consideration of only utilization or disposal at the site of the wood processing facility.
- (c) Methods of utilization which provide useful energy.
- (d) Utilization or disposal systems involving thermal processes of:
 - combustion (complete oxidation in an excess of oxygen)
 - conversion (gasification with or without charcoal, etc.)
 - degradation (pyrolysis in the absence of oxygen).
- (e) Emphasize the disposal aspect but recognize that wood is a major *renewable* energy resource and that this energy should be utilized not only in known ways but in ways yet to be conceived and reduced to practice.
- (f) Consideration of those burners or systems that are operating on a commercial scale and have a performance record.
- (g) Description of operation, performance and costs for one typical example of each alternative system.
- (h) Limitation of study to the operations of the pacific forest industry.

1.2 Purpose

- (a) To provide a state-of-the-art review of equipment and processes for the on-site disposal of wood residue from sawmills and related wood processing facilities.
- (b) To provide a review of equipment systems to allow a comparison of available alternatives for a given situation.
- (c) To provide a basis for a rational evaluation of 'costs' versus 'benefits' of reduced air pollution.
- (d) To identify areas where research and development would be beneficial.

2 INDUSTRY DESCRIPTION

2.1 General

To assess alternatives for the disposal of wood residues, it is necessary to determine the magnitude of the disposal problem, the nature of wood residue for disposal and the structure of the wood processing industry. The forest industry of British Columbia produces 68% of all lumber, more than 90% of all plywood and more than 20% of all pulp and paper made in Canada. The gross annual value from these operations is \$2.1 billion. Because the British Columbia forest industry is the largest segment of the Canadian wood processing industry it is the sector considered in this report.

Historically the forest industry has not been energy intensive, but diversification of operations has led to increasing use of all forms of energy. The trend towards higher energy use per unit product and continued increase in total forest utilization have made the industry one of the principal users of energy in British Columbia. The industry has grown from early operations in which individual mills generated their own power through combustion of wood residues, to become a major consumer of natural gas, liquified petroleum gas (LPG) and electricity. Rapidly increasing costs of non-renewable fossil fuels and the advent of new wood-burning technology is renewing interest in wood as an economical, clean and renewable, non-fossil form of energy.(8)(9)(10).

The following information provides data on the magnitude of operation to June 1973. Much of the data were provided by the British Columbia Council of Forest Industries (COFI) and affiliated associations representing some 90% of the industry. COFI is now engaged in a study to update data on production and wood residue generation.

2.2 Total Production

2.2.1 Roundwood Log Cut. British Columbia possesses 43% of the merchantable timber in Canada, amounting to 269 billion cubic feet of mature wood according to the 1968 inventory of forest land. The estimated economic annual allowable cut (EAAC) of this resource is 2935 million cubic feet, of which only 1850 million cubic feet was being utilized in 1970. The EAAC is based on a rate of utilization that will allow the forest resource to be continually regenerated without net depletion.

2.2.2 Lumber. The logical division in lumber production is between Coast and Interior. The coastal area is characterized by large centralized operations, most of which have been in operation for many years. Ease of log transport by water has favoured such major production centres. In the Interior, mills have traditionally been smaller than on the Coast and dispersed to minimize log transport costs.

Figure 1 shows actual production of softwood lumber in British Columbia and Canada up to 1971 and projects production to the year 2000. Because British Columbia produces little hardwood lumber, the value for softwood may be assumed to represent total lumber production. For conversion to roundwood volume, 1.0 ft³ is equivalent to 6 foot board measure (fbm).

Table 1 shows the growth of lumber production in the coastal and interior areas of the province from 1950 to 1972. It is evident that future growth in lumber production will be predominantly in the Interior.

TABLE 1 BRITISH COLUMBIA TOTAL LUMBER PRODUCTION, 1950-1972*

Year	Production (board feet x 10 ⁶)		
	Coast	Interior	Total
1950	2512	997	3509
1960	2850	2455	5305
1965	3649	3800	7449
1970	3790	3867	7657
1972	4026	5440	9466

*COFI data.

2.2.3 Plywood. The coastal area is currently responsible for the bulk of plywood production in the province. The large peeler logs required for the industry have been plentiful on the Coast. In recent years, however, plywood and veneer production throughout the Interior has become significant. Because coastal log cut is approaching its maximum allowable level, it may be assumed that there will be continued expansion in the Interior and limited expansion on the Coast.

Figure 2 shows actual softwood plywood production in Canada to 1971 with projections to the year 2000. It may be assumed that British Columbia produces from 90 to 95% of all Canadian softwood plywood.

2.2.4 Pulp and Paper. The division of production in this portion of the industry results in three areas:

- Southern Coastal - isolated with no access to natural gas at present;
- Interior - access to natural gas and opportunity for expansion;
- Northern Coastal - mills at Prince Rupert and Kitimat - logs drawn from both Coast and Interior - access to natural gas.

The Southern Coast is of particular interest in that it contains the bulk of existing pulp and paper capacity, yet is isolated from natural gas. The following data show the existing distribution of production capacity. This situation will not persist because the Coast is approaching its maximum allowable cut while the Interior has non-utilized timber available.

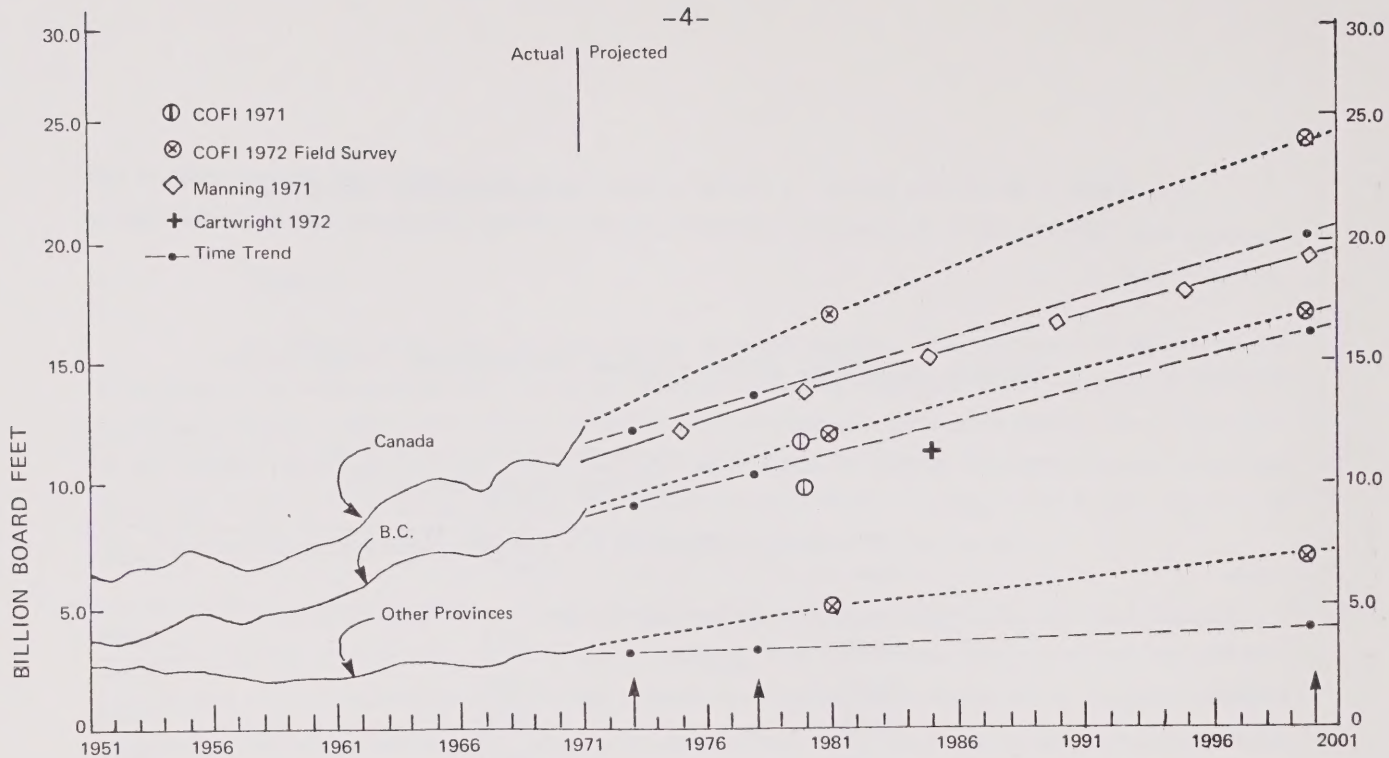


FIGURE 1 SOFTWOOD LUMBER PRODUCTION, CANADA, 1951 - 2001

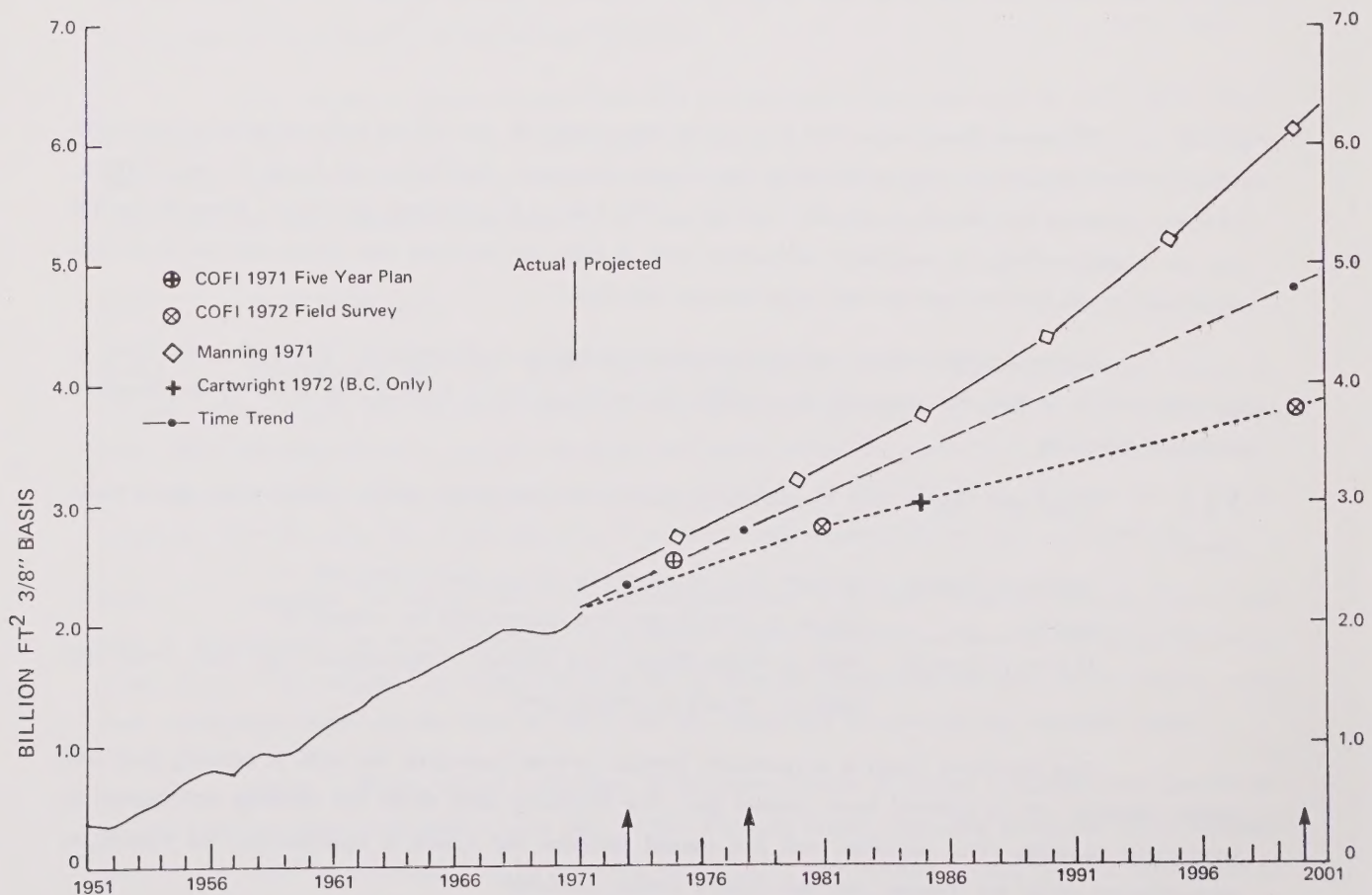


FIGURE 2 SOFTWOOD PLYWOOD PRODUCTION, CANADA, 1951 - 2001

TABLE 2 DISTRIBUTION OF PULP AND PAPER PRODUCTION CAPACITY
IN BRITISH COLUMBIA, 1972

Area	Production capacity (%)		
	Pulp	Paper	Total
Southern Coast	55.6	76.0	61.0
Remainder of British Columbia	44.4	24.0	39.0
Total	100.0	100.0	100.0

Table 3 lists pulp and paper production in the province from 1960 to 1972. Future growth in this sector is expected to parallel growth in lumber and plywood operations. On this basis, pulp and paper production will total 12 million tons by 2000. Growth may be expected through increased capacity at existing mills and through new mills serving parts of the province where timber has not yet been fully utilized.

TABLE 3 BRITISH COLUMBIA PULP AND PAPER PRODUCTION 1960-1972*

Year	Production (tons x 10 ³)	
	Pulp all grades	Paper and paperboard
1960	2125	1150
1965	3275	1539
1970	4521	1810
1972	4909	1958

*COFI data.

2.2.5 Shingles. Table 6, shows a total shingle and shake production in 1970 of 1 710 000 squares (one square is 100 ft² of laid shingles). Future growth may be expected to follow the general trend in lumber at a lower rate. Shingles are made from Western Red Cedar which is most abundant in

coastal areas. Consequently, there will not be an expansion in the Interior paralleling the lumber and pulp expansion.

2.2.6 Particle Board and Fibre Board. There is no specific material supply factor influencing growth trends in the interior and coastal areas. Production is not dependent on permissible log cut, since the raw material used is a wood residue. Therefore, expansion will occur as the market permits.

British Columbia has two particle board plants with a combined capacity of 60 million square feet per year of 3/4-in. board. The Vancouver plant has operated steadily, while that at Grand Forks has experienced shutdowns.

Canadian shipments of particle board in 1972, totalled 265 million square feet having risen from 47 million square feet in 1962. The trend in Canada appears to be a doubling of production each five years.

British Columbia produced 180 million square feet of 1/8-in. fibre board in 1972.

2.3 Predictions for Future Production

Table 4 summarizes projections for forest industry production in 1992. A 20-year projection has been used because this is the period within which the EAAC is expected to be reached, and projections beyond 1992 are not certain.

3 ENERGY AND FUEL REQUIREMENTS OF THE FOREST INDUSTRY

3.1 Total Requirements, 1970

Data from Statistics Canada are summarized in Tables 5 and 6 and show the quantities of each type of fuel and energy used in each branch of the industry with the exception of hog fuel. It will be observed that fuel oil is the single largest source of energy, reflecting the dependence of Vancouver Island and certain coastal pulp mills (natural gas is not available at these mills). It can also be seen from Table 6 that the pulp mill sector consumes the greatest portion of fuel oil.

It is interesting to note that the forecast of British Columbia natural gas requirements for 1973 was 144.7 billion cubic feet, even with the limited distribution of gas in the forest industry. The industry, therefore, currently consumes about 13.5% of the domestic requirement.

3.2 Trends by Area of Province

It can be seen from Table 6 that the industry, as of 1970, was strongly dependent on fuel oil. More recent data show that the same situation existed in 1973. The bulk of the oil is consumed in the pulp and paper sector, particularly by mills on Vancouver Island. The Vancouver Island mills would convert to natural gas if it were available at a competitive price. This price would have to provide for recovery of substantial conversion costs.

TABLE 4 PROJECTIONS TO 1992 FOR BRITISH COLUMBIA FOREST INDUSTRY PRODUCTION*

Item	1972	1992
Total lumber cut (billion fbm)	9.5	14.0
Coast	4.0	5.0
Interior	5.5	9.0
Total plywood (billion square feet)	2.0	3.2
Pulp and paper (million tons)	6.87	10.0
Coast ¹	4.50	5.5
Interior	2.37	4.5
Shingle (million squares)	1.71	1.71
Particle board (million square feet 3/4-in.)	50	200
Fibre board (million square feet 1/8-in.)	180	180

*Projections are on basis of actual production, not of installed production capacity (COFI data).

¹Coast refers to Vancouver Island, Powell River, Ocean Falls and Vancouver, but excludes Prince Rupert and Kitimat.

3.3 Projection of Fuel and Energy Requirements to 2002

The projections in Table 7 are made on the following premises:

- there will be no major change in availability and relative cost of fuel;
- fuel and energy requirements are tied to total production (approximately 100% increase 1970 to 1992);
- the relative increase in lumber and plywood cut, and in pulp and paper production will be the same;
- automation and process changes will result in a 1.5 %/year increase in electrical energy requirements per unit of production in all industry operations. Assume this is a linear increase based on 1972 unit use.
- unit use of gas, oil and LPG remain constant.

Electrical energy is either purchased from British Columbia Hydro or is generated in plant facilities. The latter situation represents a minor portion of total requirements, and this portion will tend to decrease as the industry expands. The purchase of natural gas, fuel oil and LPG represents the purchase of heat energy. These fuels cannot be used interchangeably but for the purpose of this report

TABLE 5 FUEL AND ENERGY REQUIREMENTS AND PRODUCTION IN BRITISH COLUMBIA SAWMILLS AND PLANING MILLS, 1970*

Item	Unit	Coast		Interior	
		Quantity	Value (\$)	Quantity	Value (\$)
Fuel oils	gal	2 957 941	405 422	7 647 518	1 522 072
Natural gas	MCF ¹	21 175	12 188	1 459 248	967 831
LPG	gal	181 546	35 018	4 677 133	605 373
Electricity purchased	kWh	297 824 051	3 040 879	346 701 370	4 590 788
Steam purchased	lb	464 328 000	305 059	234 234 483	251 665
Total lumber	Mfbm	3 514 872		3 725 108	

* Statistics Canada data

¹ MCF - thousand cubic feet

will be regarded as different sources of heat energy. The effects of fuel availability and cost are considered in later sections.

Individual projections will change as natural gas is made available to major new areas but the Btu projection should remain the same.

4 SOURCES OF ENERGY

4.1 Fuel Oil

Fuel oil is currently the major purchased fuel in the industry. This situation exists primarily because natural gas is not available in some areas of the province, notably Vancouver Island and the contiguous mainland. If natural gas were available at all mills at a competitive price, the mills would elect to use natural gas because:

- it produces clean stack gases
- it is simpler to burn than fuel oil
 - (no sludges or ash)
 - (no preheating steam required)
- it can be fired directly into lumber and veneer dryers.

TABLE 6 FUEL AND ENERGY CONSUMPTION IN THE BRITISH COLUMBIA
FOREST INDUSTRY, 1970*

	Quantity	Value (\$)
Veneer and Plywood Mills		
<i>Fuel</i>		
Fuel oils	1 232 772 gal	117 282
Natural gas	839 957 MCF	429 623
LPG	674 793 gal	126 878
Other		163 984
Electricity purchased	236 063 600 kWh	2 043 929
Steam purchased	1 393 761 420 lb	636 515
<i>Production</i>		
Plywood (3/8 in)	1 684 464 M sq ft	138 478 807
Veneer (1/8 in)	1 484 729 M sq ft	16 118 500
Shingle Mills	29 553 MCF	20 529
<i>Fuel</i>		
Fuel oil	16 984 gal	4 614
Natural gas	29 553 MCF	20 529
LPG	3 294 gal	797
Electricity purchased	18 478 210 kWh	273 947
Steam purchased	no data	
<i>Production</i>		
Shingles not further processed	1 028 387 squares	
Shingles further processed	309 707 squares	
Shakes	371 906 squares	
Pulp chips	69 460 units	
Pulp and Paper Mills		
<i>Fuel</i>		
Natural gas	16 837 696 MCF	6 958 017
Fuel oil	166 320 990 gal	13 126 074
LPG	904 279 gal	169 871
Other	-	2 283 745
Electricity purchased	3 227 157 655 kWh	17 432 514
<i>Production</i>		
Pulp	4 518 735 tons	
Paper and paperboard	1 845 678 tons	

* Statistics Canada data

TABLE 7 PROJECTION OF FUEL AND ENERGY REQUIREMENTS IN THE BRITISH COLUMBIA FOREST INDUSTRY

	Unit	1970		1992		2002	
		Quantity	Equivalent Million Btu	Quantity	Equivalent Million Btu	Quantity	Equivalent Million Btu
Fuel oil	gal	178 176 200	31 300 000	357 000 000	62 700 000	400 000 000	70 000 000
Natural gas	MCF	19 188 000	19 188 000	38 376 000	38 376 000	43 200 000	43 000 000
LPG	gal	7 173 580	783 000	14 346 000	1 560 000	16 100 000	1 760 000
Electricity	MkWh	4 152 740	14 100 000	9 677 000	32 900 000	11 220 000	38 500 000

NOTES:

- For convenience, 1972 requirements may be assumed to be about 10% greater than 1970 requirements, reflecting a high rate of expansion in recent years.
- Projections are based on the ratios of probable total lumber cut at the various times (See Figure 1).

TABLE 8 SOME TYPICAL FUEL AND ENERGY PURCHASE COSTS IN BRITISH COLUMBIA, 1972*

Area	Mill	Fuel	Yearly quantity	Unit price	Unit price/ MM Btu at burner tip ¹ (\$)
Interior	21	Natural gas	100 000 MCF	\$0.85/MM Btu	1.00
	22	Natural gas	58 600 MCF	\$0.90/MM Btu	1.06
	26	Natural gas	2 713 000 MCF	\$0.45/MM Btu	0.53
	26	Fuel oil	8 277 000 gal	\$0.11/gal	0.78
	25	Fuel oil	199 000 gal	\$0.171/gal	1.22
	21	Electricity	12 000 000 kWh	1.24¢/kWh	-
Coast	25	Electricity	39 130 000 kWh	0.80¢/kWh	-
	3	Natural gas	271 710 MCF	\$0.39/MM Btu	0.46
	15	Natural gas	75 500 MCF	\$0.44/MM Btu	0.52
	19	Natural gas	2 566 MCF	\$0.705/MM Btu	0.83
	3	Fuel oil	236 000 gal	\$0.172/gal	1.23
	1	Fuel oil	222 000 gal	\$0.196/gal	1.40
Vancouver Island	1	Electricity	10 000 000 kWh	1.00¢/kWh	-
	2	Electricity	1 267 000 kWh	1.80¢/kWh	-
	36	Fuel oil	28 397 000 gal	\$0.095/gal	0.68
	38	Fuel oil	12 669 000 gal	\$0.097/gal	0.70
	41	Fuel oil	347 000 gal	\$0.123/gal	0.88
	36	Electricity	601 290 000 kWh	0.52¢/kWh	-
	35	Electricity	9 770 000 kWh	1.27¢/kWh	-
	39	Electricity	65 100 000 kWh	0.68¢/kWh	-

*From COF1 survey, 1973

¹Burning efficiency of gas

= 85%

Burning efficiency of fuel oil

= 80%

TABLE 9 FUEL COST COMPARISON OF SOME INDUSTRIAL FUELS IN BRITISH COLUMBIA, AUGUST 1974

Fuel type	Unit	Cost/ unit (\$)	Heating value /unit (MM Btu)	Cost (\$/MM Btu)	Assumed steam gen. efficiency (%)	Fuel cost (\$/MM Btu)
Oil - #5 Fuel oil ¹ (Mainland & Int.)	barrel	11.30	6.3	1.82	80	2.27
#6 Fuel oil	barrel	10.50	6.3	1.64	80	2.05
Natural gas ²						
Lower mainland						
Firm, over 20,000/month	therms	0.0865	0.1	0.865	76	1.14
Interup, over 150,000/month	therms	0.0550	0.1	0.55	76	0.72
Interior						
Firm, over 300,000/month	therms	0.065	0.1	0.65 winter	76	0.85
Interup, over 300,000/month	therms	0.055	0.1	0.55 winter	76	0.72
Wood-bark residue						
Douglas Fir sawdust	unit ³	4.00 ⁴	16.9 ⁵	0.237	66 ⁶	0.36
Western Hemlock sawdust	unit	4.00	14.3 ⁵	0.280	58 ⁶	0.48
Douglas Fir hogged bark	unit	4.00	24.4 ⁵	0.164	67 ⁶	0.24
Western Hemlock hogged bark	unit	4.00	19.6 ⁵	0.204	66 ⁶	0.31

¹No. 5 oil at \$0.323 per imperial gallon.²B. C. Hydro and Power Authority.³Unit is 200 ft³ bulk volume assumed to contain dry, 1900 lb of Douglas Fir sawdust, 1700 lb of Western Hemlock sawdust,

2600 lb of Douglas Fir bark and 2200 of Western Hemlock bark.

⁴Assumed cost delivered to user (equivalent to trucking in a 25 to 50 mile radius)⁵Higher heating values per lb, dry, assumed: Douglas Fir sawdust 8900, Western Hemlock sawdust 8400, Douglas Fir bark 9400,

Western Hemlock bark 8900.

⁶Efficiencies assumed 40% excess air, 500° F stack temperature, fuel moisture 120% (dry basis) for Western Hemlock bark,

80% (dry basis) for the others.

Table 8 summarizes typical fuel costs in three areas of British Columbia. These data demonstrate the variation in price resulting from volume of fuel and geographical location. Fuel costs as of August 1974, have been tabulated in Table 9 for comparison.

The forest industry is concerned with the continued availability of fuel oil. Seventy percent of the province's fuel oil requirements are supplied by imports from the United States, chiefly in the form of heavy residual fractions. The energy crisis in the United States will tend to curb the export of fuels from that country. Under such conditions, the forest industry cannot anticipate assurance of long-term oil supplies and if oil imports were cut off there are no alternate fuel sources for major portions of the industry.

4.2 Natural Gas

Tables 5 and 6 show that even in areas where maximum residue utilization is in effect, major sources of supplementary fuel are now necessary and requirements will increase as the industry expands.

Mill size in the interior of the province has increased over the past 10 to 20 years with a consequent decrease in number of mills. More recently, there are indications that the trend will be at least partially reversed with more small mills being installed to achieve maximum lumber utilization. It should be recognized that the term 'small' does not mean a return to the crude, small mills which were prevalent in much of the Interior some years ago, but rather, economic units handling in the range of 50 000 to 150 000 fbm/day. These mills will require electricity and gas for successful operation.

Total natural gas use in British Columbia in 1973 has been estimated at 144.7 billion cubic feet. The prediction for 1992 is 285.3 billion cubic feet. The forest industry in 1972 was estimated to have consumed 21 billion cubic feet or about 15% of the provincial total. In 1992, the industry will consume about 38 billion cubic feet, 13% of the total. The industry values are based on extrapolations of existing usage, a conservative method in view of existing trends in the industry to increase natural gas use.

4.3 Coal

The forest industry has not been a major user of coal; however, the changing role of energy sources justifies a few brief comments. Although Canada and the United States have vast resources of coal, a recent report by Biswas (11) indicates that the use of coal has dropped from 58.1% of the energy consumption in Canada in 1945, to 13.6% in 1969. Supplies remain plentiful, but problems of transportation and environmental control have contributed to its decline as a primary fuel. Unlike coal, oil and gas are valuable raw materials in the chemical and petrochemical industries. As the costs of oil and gas increase, heavy industry will probably tend towards the use of coal. There is considerable activity in converting coal to feedstock liquid and to low-, medium- and high-Btu gas.

There are five processes operating (and eight pilot plant processes) for production of medium- to high-Btu gas from coal and two processes operating (and six pilot plant processes) for

production of low-Btu gas. A Lurgi coal gasification unit has been operating in Edinburgh, Scotland for a decade. In late 1974, commercial-scale methanation of this low-Btu gas was successfully demonstrated. The synthetic natural gas (SNG) produced was blended with natural gas in a 60:40 ratio and consumed by regular gas users without incident. These new technologies are not expected to have much impact until early 1980, and would require substantial investments in mining and converting facilities.

4.4 Wood

Wood is becoming increasingly attractive as an energy source. A recent report by Biswas (11) notes that in Canada the contribution of wood to primary energy consumption has dropped from 12% in 1945 to 2% in 1969. Wood is a *renewable* source of energy. In effect, the growth of wood constitutes the recycling of carbon dioxide in the atmosphere and the capture (and storage) of solar energy. In fact, Szego and Kemp (9) study the economics of growing wood for its energy value. They conclude that fuel produced in an energy plantation is likely to cost about \$1.00 per million Btu and be competitive with other fuels. Their work is based on solar radiation conversion to fuel efficiencies of about 0.4 to 1.0%. Evans (10) criticizes this solar-energy conversion approach and advocates assessment by direct use of available forest productivity (biomass) data. Data from the Pacific Northwest suggest that Red Alder has exceptional productivity and that an electric power plant generating 150 MW might be sustained by a plantation of 65 square miles on a 10 year growth cycle. In other regions, areas of 240 square miles or more would be needed.

Table 9 provides a comparison of the cost of some industrial fuels in British Columbia as of August 1974. Estimates are also given for fuel costs for steam generation. Assumptions made by Corder (2) are used to allow comparison of costs in Oregon in November 1971. They also allow comparison with costs in British Columbia in 1972, listed in Table 8. The sharp increase in oil and gas prices reflects the effect of the 'fuel crisis' of 1973-74 when oil exporting nations limited exports.

While fuel costs using wood residues are substantially less than oil or gas, several important factors must be considered:

- (a) Prices for fuel depend on location and on local supply and demand. In 1970 hog fuel¹ delivered to coastal pulp mills cost \$3.75 to \$4.50/unit. In August 1974, hog fuel purchased by a sawmill on the lower mainland of British Columbia cost \$1.50/unit. In some areas of the Interior, hog fuel may incur an expense when landfill is used for its disposal. In the Pacific Northwest of the United States, availability of oil and gas was limited in the spring of 1974. In addition, oil costs almost tripled those of summer, 1973. Hog fuel was in demand as a replacement fuel and prices increased substantially. In the summer of 1974 oil again became available in the Pacific Northwest and mills decreased hog fuel purchases.
- (b) For a given heat content, hog fuel is heavier and bulkier than oil. Transportation costs are a limiting factor. Truck hauling costs can be about ten cents per mill per unit and, consequently, to haul hog fuel 50 miles would cost about \$5.00/unit.

¹Hog fuel - waste wood hogged in a hammer mill to comminute it prior to burning. It consists of bark, sawdust, shavings, splints and chips, and usually has a moisture content near 50%.

- (c) Because hog fuel is bulky and has a high moisture content, steam plants using it cost more than steam plants using gas or oil. Table 10 lists the costs estimated in 1970 for an 80 000 lb/h boiler installed on the coast of British Columbia.

TABLE 10 BOILER FUEL COST COMPARISON, 1970

Item	Cost (\$)	
	Oil fired	Hog fuel fired (Pollution controls not included)
Basic boiler	160 000	320 000
Fuel handling	30 000	120 000
Piping	80 000	80 000
Building	70 000	100 000
Sundry	30 000	30 000
Total	370 000	650 000

The above figures are cited to illustrate the order of magnitude of costs and should not be assumed to apply to any specific situation. It can be seen that a hog fuel-fired boiler costs twice as much as a boiler burning oil. A small, automated wood or bark-fired boiler system including a fuel storage silo and fuel dryer costs about four times as much as the same-sized, oil-fired boiler. So, while hog fuel has the lower basic fuel cost, the increased capital cost burden requires careful consideration when assessing the economic feasibility of hog fuel firing.

Where energy demands are large, and interruptible natural gas is available, it is financially more attractive to use gas-fired kilns and gas-fired steam generating equipment even though surplus hog fuel is available on site. The hog fuel then poses a disposal problem. Recent developments in wood residue burning, however, are providing systems which produce relatively clean combustion gases that may be used directly. If the heat available in wood residues exceeds demand, and excess wood fuel has no market, these new systems allow excess heat to be dumped to the atmosphere in compliance with emission regulations. These units do not require expensive steam boiler installations, thereby decreasing the capital cost burden. On-site disposal is now possible with the opportunity of utilizing some of the available heat to effect a saving in operating costs. It is vital, however, to determine the nature of the incombustible inorganic matter present in the wood residue to be burned. For instance, river silt or salt can pass through the combustion system and conventional gas cleaning equipment. One way of

overcoming this problem is to remove these residues as a slag from the burners. This process is now (September 1974) being tested in a cyclone suspension burner on a commercial scale.

5 WOOD RESIDUES AS AN ENERGY SOURCE

5.1 Background

The principal coastal lumber mills consume most of their own wood residues to generate steam and power. Smaller mills supply the extra requirements of the large lumber mills and of pulp and paper mills. Mills with power plants have tended to upgrade their facilities over the years to achieve more efficient production of steam and electricity.

Pulp and paper mills generate much of their own steam from their waste products. They are not major waste producers, however, and depend on outside waste wood and supplementary fuels.

Few newer sawmills are installing steam generating facilities, and in-plant electrical generation is virtually non-existent. There are a number of reasons for this trend:

- the capital cost of a steam and electrical plant is prohibitive in any but very large sawmills;
- a sawmill can be operated satisfactorily on purchased electricity and natural gas (or LPG);
- the cost of electricity from a small generating plant is not competitive with purchased power.

5.2 Quality of Wood Residues

Wood residue quality depends on method of transport, method of storage and the area in which it is generated. Quality also varies with season.

A coastal mill using logs stored and transported in seawater will produce hog fuel with a moisture content of 55 to 65% (total weight basis) and a high salt content. A similar mill on the Fraser River will produce a waste with the same moisture content but with little salt. An interior mill using dry-land sorting and mechanical debarking will produce waste with 45 to 55% moisture content and no salt.

For estimation purposes, an average moisture content of 55% and a gross heating value of 17 million Btu/unit of hog fuel may be assumed. This means that one unit of typical hog fuel, burned in a boiler, will yield 8.5 million Btu of useful thermal energy.

5.3 Distribution of Residue Production

The British Columbia Forest Service has provided sawmill size distribution data for coastal and interior mills as of winter 1973-74. There are six forest districts in British Columbia, five of which are in the Interior. Information on mill size distribution for the Interior Quesnel Forest District (Clinton to

Quesnel) is not included. Operations in the Quesnel District are not much different from the neighbouring Kamloops District; consequently, the distribution of wood residue will not be greatly affected although the total number of mills and amount of residue will be low.

The distribution of wood residue production provides an indication of sizes and types of disposal facilities required for various circumstances. This distribution has been calculated based on the following conversion factors and assumptions:

(a) Basis of estimate (Appendix)

Solid wood residue produced	100 ft ³ /600 fbm
Quantity hogged wood residue (gravity packed)	0.55 units/100 ft ³ solid
Unit of hogged wood	200 ft ³ /unit
Volume of hogged wood produced ¹ (bark, sawdust & shaving)	916.7 units/million fbm
Weight of dry wood residue ² (2000 lb dry wood/unit)	1.83 lb/fbm
Assume sawmills operate at the following rate	
0 to 40 000 fbm/shift	1 shift/day
40 000 to 100 000 fbm/shift	2 shifts/day
100 000 to 400 000 fbm/shift	3 shifts/day

(b) Calculation example

Data	- mill size range	40 000 to 50 000 fbm/shift
	- number of mills in this size range	7

Calculations -

Average production for size range	45 000 fbm/shift
Volume of residue =	
(45 000) (2 shift/day) (7) (916.7 units)	= 577.5 units/day
1 000 000 fbm	

The rate of wood residue production has been calculated as shown above for each 10 000 fbm/shift interval of capacity of sawmills in British Columbia. Figure 3 shows the distribution for coastal and interior sawmills. Estimated wood residue production (bark, sawdust and shavings) is summarized in Table 11.

¹For bark and sawdust only, Bramhall (1) reports 550 units/million fbm based on 57% mc (dry basis).

$$\begin{array}{rclcl}
 2 & \frac{0.55 \text{ units}}{1000 \text{ ft}^3} & \frac{2000 \text{ lb dry wood}}{\text{unit}} & \frac{100 \text{ ft}^3}{600 \text{ fbm}} & = 1.83 \text{ lb/fbm}
 \end{array}$$

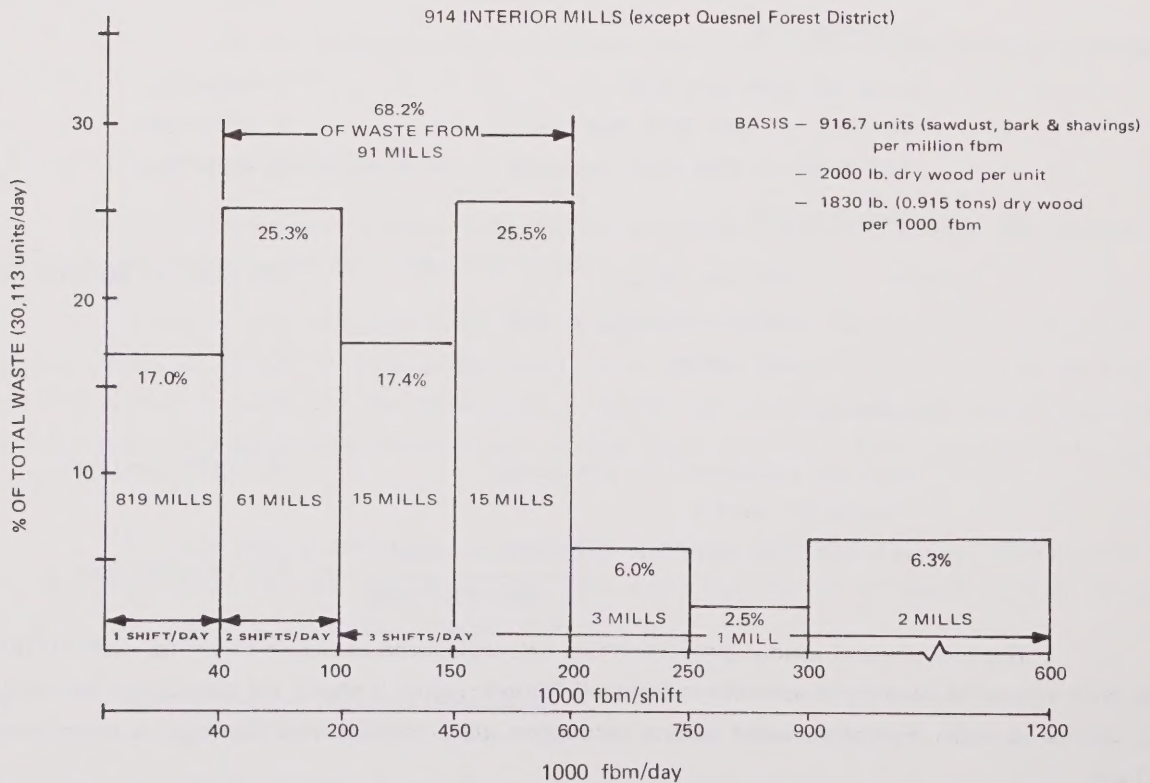
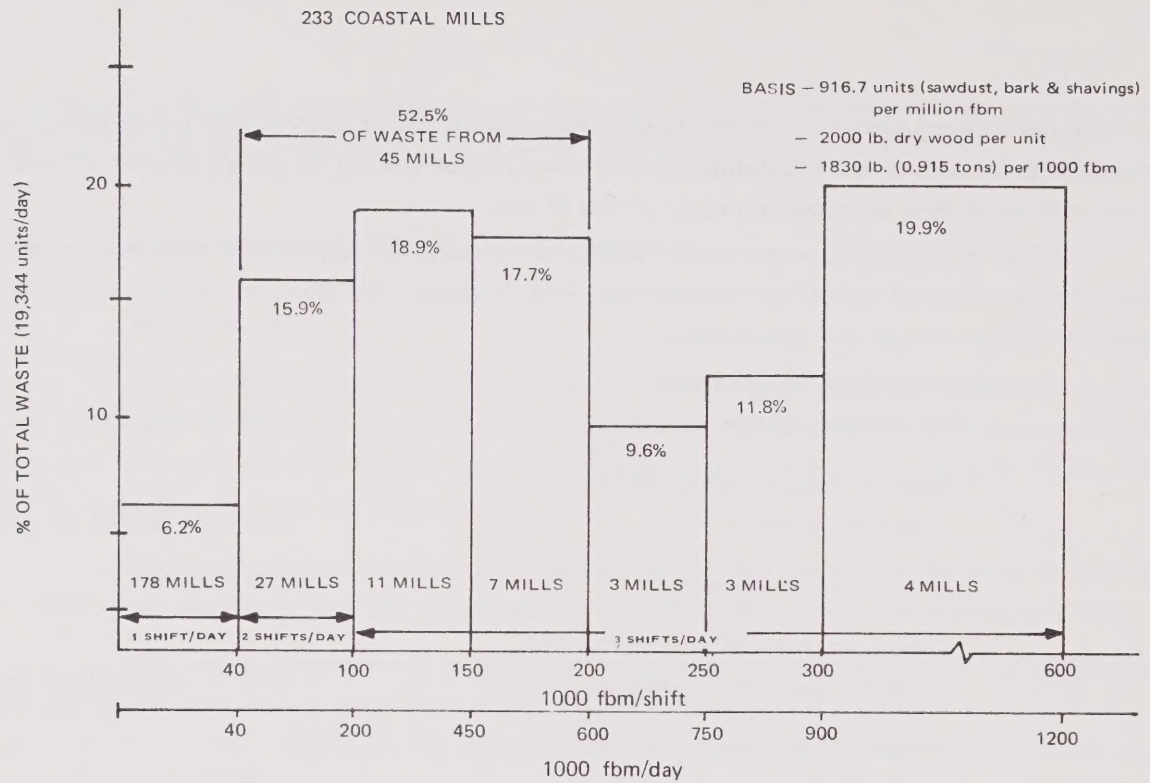


FIGURE 3 DISTRIBUTION OF WOOD RESIDUE PRODUCTION IN BRITISH COLUMBIA

TABLE 11 WOOD RESIDUE PRODUCTION FROM SAWMILLS IN BRITISH COLUMBIA

			Wood residue production	
Mill capacity fbm/shift	Number of mills	Fraction of total number %	Amount units/day	Fraction of total residue %
Coastal mills				
0 - 40 000	178	76.4	1 191	6.2
40 000 - 200 000	45	19.3	10 160	52.5
200 000 - 300 000	6	2.6	4 135	21.4
300 000 - 400 000	4	1.7	3 858	19.9
Total	233		19 344	
Interior mills				
0 - 40 000	819	89.4	5 212	17.0
40 000 - 200 000	91	9.9	20 359	68.2
200 000 - 300 000	4	0.44	2 615	8.5
300 000 - 400 000	2	0.26	1 929	6.3
Total	916		30 115	

Points to note from the distribution are:

- six to 17% of wood residues are produced by a large number of mills cutting less than 40 000 fbm/shift and producing less than 6.5 units/day per mill (average);
- the majority of wood residue (particularly in the Interior) is produced by mills in the 40 000 - 200 000 fbm/shift (2 shift-day) size;
- the majority of waste is produced by less than 100 mills generating 37 tons dry wood residue per day (40 000 fbm/shift) to 183 tons dry wood per day (200 000 fbm/shift);
- although the data in Figure 3 show the distribution of sawmills in British Columbia, it is presumed that this distribution will be comparable in other parts of Canada;
- distribution data were developed to indicate the size of thermal decomposition units needed to dispose of wood waste generated by sawmills.

There is an increasing trend for mills to convert marketable residue to sawdust and chips for sale to pulp mills. Lower quality residues, such as bark, remain at the mill site. Therefore, the quantity of residue for disposal will tend to be smaller than that in Figure 3.

Residue from sawmilling consists of 13% of the log as sawdust, 10% as shavings and 12% as bark. If all sawdust and shavings were segregated for shipment to pulp mills, particle board plants, etc., residue would only be $12/35$ or 34% of the quantity shown. If half the available sawdust and shavings were segregated, residue would be $(12 + 11.5)/35$ or 67% of the amount in Figure 3.

5.4 Volumes of Wood Residues in British Columbia

Most wood residues result from sawmill, plywood mill and shingle mill operation. Table 12 shows the volumes of wood residues produced in British Columbia in 1969. It is possible to project waste production to 1992 and 2002 on the basis of either roundwood or lumber plus plywood cut. In making such estimates three factors must be considered:

- increased utilization of small trees results in proportionately more bark and other wastes than occurred with large trees. Hence, waste volume per unit of roundwood cut should increase;
- improved recovery methods will decrease the amount of actual wood waste (bark remains constant);
- increased utilization of wood residues will reduce the amount of waste available for burning.

It is assumed that a constant ratio between waste available and wood cut will persist for the projection period.

On the above basis, the volume of wood residues that will be produced in British Columbia in 1992, is estimated at 20.0 million units/year.

Table 13 presents results of a 1972 wood waste survey of the Lower Coast. It can be seen that 82% of the residue was used for fuel. The remaining 18% includes material extracted for pulping (sawdust, shavings), fuel sales outside the province, feed to particle board plants and bark mulch. It is estimated that this area utilizes about 95% of its residue.

5.5 Utilization of Wood Residues

Tables 13 and 14 indicate the extent of residue utilization in coastal British Columbia. The data must be used with caution because the Lower Mainland and Vancouver Island are almost balanced in production and consumption of hog fuel, with most pulp mills purchasing large quantities of hog fuel from their affiliated lumber operations or from other companies who do not have facilities to utilize hog fuel. In this respect Tables 13 and 14 may be misleading if the data are extrapolated without consideration of specific factors affecting the total area.

TABLE 12 TOTAL WOOD RESIDUES IN BRITISH COLUMBIA FROM SAWMILLING AND PLYWOOD OPERATIONS, 1969

Type	Weight %	Units ¹ /year
Bark	28	2 920 000
Sawdust	34	3 540 000
Shavings	26	2 700 000
Others	12	1 240 000
Total		10 400 000

¹ Unit = 200 ft³ of gravity compacted waste

= 2000 lb dry wood approx.

Ratio of waste to log cut = 0.55 units/cunit approx.

1 Cunit = 100 ft³ solid wood

= 600 fbm

TABLE 13 HOG FUEL STUDY FOR LOWER COAST OF BRITISH COLUMBIA, 1972*

Year	Volumetric Units (200 ft ³ gravity compacted)		
	Production	Consumption as fuel	Other uses ¹
1972	3 600 666	2 931 916	668 750
1977	3 987 718	3 090 998	896 720
1982	4 012 347	3 098 798	913 549
1987	4 018 952	3 103 498	915 454
1992	4 019 577	3 101 698	917 879

*Covered 51 lumber and plywood mills and 9 pulp mills

¹Feed for pulp mills, bark mulch, fuel sales, etc.

TABLE 14 TYPICAL METHODS OF WOOD RESIDUE DISPOSAL IN
BRITISH COLUMBIA*

Disposal method	Units/Year		
	Vancouver Island	Greater Vancouver	Outside
Steam production	387 339	373 875	681 117
Product manufacture	57 950	97 700	11 310
Incineration	0	27 689	218 050
Dumping, sale, etc.	249 028	352 721	420 291
Total	694 317	851 985	1 330 768
Waste production (units/cunit)	0.556	0.594	0.475
Steam production (1000 lb/unit waste)	5.5	4.4	4.9

* From data on 49 mills

In predicting the amount of economically useful hog fuel production, the location of waste production must be considered. Many smaller mills are so far from installations which could utilize their waste that transportation is economically unfeasible. In specific areas with concentrations of mills, however, central utilization of waste may be justified because transport costs are low.

Data indicate that there will be an overall surplus of hog fuel in 1992, and in 2002. Table 15 contains data on existing and projected utilization of wood waste. The information presented is based on the best available data but must be used with caution. For example, the major expected increase in waste production will be in the interior of the province where there are major reserves of non-utilized forest. If, for any reason, the development of these forests does not occur within the projection period, the data will be grossly high.

In 1972 the industry utilized 95% of its waste in the coastal area and only 50% in the Interior. This position reflects the historical trend for coastal sawmills and plywood mills to install their own steam and electrical plants, and the low-cost barge transportation of hog fuel from primary producers to pulp mills and large sawmills.

Industry projections (COFI) for typical coastal mills indicate a 95% utilization in 1992. Data are not available that would allow the use of any value but 50% for interior operations in 1992.

TABLE 15 EXISTING AND PROJECTED UTILIZATION OF WOOD RESIDUE IN BRITISH COLUMBIA

	1972		1992		2002	
	Coast	Interior	Coast	Interior	Coast	Interior
Amount produced (units)						
(a) Equivalent gross HV ¹ (MM Btu)	5 100 000	6 900 000	6 000 000	14 000 000	6 500 000	17 500 000
(b) Available HV (MM Btu) ²	87 000 000	117 000 000	102 000 000	238 000 000	111 000 000	298 000 000
Amount used for fuel (units)						
(a) Equivalent gross HV (MM Btu)	43 500 000	58 500 000	51 000 000	119 000 000	55 500 000	149 000 000
(b) Available HV (MM Btu)	4 160 000	3 450 000	4 900 000	7 000 000	5 300 000	8 750 000
Amount surplus for fuel (units) ³						
(a) Equivalent gross HV (MM Btu)	71 000 000	59 000 000	83 500 000	119 000 000	90 500 000	149 000 000
(b) Available HV (MM Btu)	35 500 000	28 500 000	42 000 000	59 500 000	45 000 000	74 500 000
Amount surplus (units)	940 000	3 450 000	1 100 000	7 000 000	1 200 000	8 750 000
Amount surplus for fuel (units) ³	255 000	3 000 000	255 000	6 000 000	255 000	7 250 000
(a) Equivalent gross HV (MM Btu)	4 300 000	51 000 000	4 300 000	102 000 000	4 300 000	123 000 000
(b) Available HV (MM Btu)	2 150 000	25 500 000	2 150 000	51 000 000	2 150 000	61 500 000
Total combined production (units)	12 000 000		20 000 000		24 000 000	
Equivalent available heat (MM Btu)	102 000 000		170 000 000		204 000 000	

¹ Heat value.

² Available heating value is based on 50% efficiency in converting wood residue to useful thermal energy.

³ The amount here is that material remaining as potential fuel when all other 'surplus' has been utilized.

5.6 Value of Wood Residue Utilization

At present, wood residues are burned to produce thermal energy. Such utilization reduces the purchase of other fuels, and in some areas (notably Vancouver Island and the Lower Mainland) virtually complete use of wood residues has been achieved. In theory, the industry surplus (beyond that already burned or otherwise utilized) could be used to further reduce consumption of gas, oil and LPG. The utility of this practice is dependent upon a number of factors:

- the capital cost of a hog fuel-fired boiler and attendant pollution control devices is considerably higher than that of a fossil fuel-fired boiler; however, lower fuel costs can offset the initial investment to varying degrees depending on the scale of operation;
- wet hog fuel must have supplementary fuel to ensure proper combustion and it is much cheaper and simpler to use only the supplementary fuel in individual installations;
- up to the present, hog fuel has not been suitable for direct-fired lumber and veneer dryers;
- modern sawmills can operate without a source of steam, but always require electricity;
- many mills do not dry their product and hence require only electricity for plant operation.

In view of the above problems in utilizing wood waste at source, it is preferable to consider a situation whereby all operations not able to economically sustain an in-plant steam and electrical generating operation would transport their wastes to central generating plants. Such plants would be large enough to generate electric power for sale to the British Columbia Hydro power grid. Individual plants would buy back this power, as required, at prevalent rates.

No scheme of this type can recover all wastes. Even Vancouver Island with its effective transport system encounters local surpluses, and the value of wood residues does not warrant transport over major distances.

5.7 Energy Requirements for a Sawmill

A sawmill requires energy in several forms for its various processes. Heat energy is required for drying lumber and for space heating of the mill. Electricity is needed to run equipment.

A sawmill producing 100 000 fbm of lumber per day produces 34 tons of dry sawdust, 31 tons of dry bark and 27 tons of dry shavings each day, a total of 92 tons of dry wood residue per day. This residue (at 50% moisture content) represents 960 million Btu of useful thermal efficiency when converted in a typical hog fuel-fired boiler.

The mill's dry kilns require 230 million Btu/day. This represents 24% of the total energy available. Space heating of the mill requires 13.6 million Btu/day or 1% of the energy available. Electrical power requirements vary depending on the number of shifts run but are about 46 000 kWh. Allowing

for normal conversion efficiencies, this requires 550 million Btu of useful thermal energy converted to electricity, representing 35% of the total available energy. The total energy required for the 100 000 fbm mill is 795 million Btu or 82.8% of the total available useful thermal energy. Sawdust, shavings and bark therefore provide a surplus of energy.

If the mill sold all the sawdust and shavings to a pulp mill, then the bark remaining would produce only 540 million Btu or 68% of the energy needed by the mill. In this case, bark alone would not provide the energy required for a 100 000 fbm/day mill.

5.8 Economics of Central Steam and Power Generation

Various studies have been made of the possibility of generating power at centralized plants using wood residues from a number of mills. Carroll, Hatch and Associates Limited have recently assessed the economics of various-sized, hypothetical plants in the Interior. They concluded that a mill or group of mills can contemplate profitable central steam generation if:

- British Columbia Hydro purchases surplus power
- existing utilities cost:
 - gas - \$0.70/MCF
 - electricity - \$0.011/kWh
- lumber cut (or equivalent) - 150 MM FBM/year.

They indicate that a 30 000 kW plant would cost about \$7.0 million exclusive of fuel handling equipment (hogs, etc.).

This subject requires further study to establish the utility of the central plant concept for the interior sector of the industry.

6 TRANSPORTATION COSTS

Transportation costs are a significant factor in the utilization and/or disposal of wood residues. When shipper and receiver are on navigable waters, barging is usually the most economical transport for wood and bark residues. Rates are established by bidding and depend on distance, volume and navigation conditions. A charge of \$2.00 to \$2.15/unit for 70 miles is typical, based on 2000 lb dry weight in barges of 450 unit capacity. Barges holding up to 950 units are used in British Columbia.

Rail cars are widely used to move wood chips and hogged bark. Rates vary with rail lines and location. Charges of \$4.40/unit for 48 miles, \$8.35/unit for 101 miles, and \$9.70/unit for 193 miles are typical for 50-ft cars containing 29.5 units/car.

Trucks offer versatility and can be self-unloading, but economic factors usually limit truck hauling to about 100 miles. Typical costs for transporting hogged fuel (4000 lb/unit) on a 2 shift per day basis using tandem-rear-axle tractor and trailers with a pay load of 45 500 lb, would be \$1.30/unit

for 10 miles; \$2.66/unit for 25 miles; \$5.78/unit for 60 miles; and \$11.76/unit for 125 miles. The above costs were taken from a paper by Hyde and Corder (3) which provides cost calculations to February 1971. Pipeline transport of wood chips to pulp mills has been tested and appears to be competitive.

To keep fuel costs at about seventy-five cents per million Btu (hog fuel at \$10.00/unit), shipment from small suppliers to large consumers such as a central power generating facility, is indicated as follows: by truck to about 100 miles, by rail to about 200 miles, and by barge if farther. If distance is over 200 miles, the possibility of trucking to transfer stations and pipelining to a central facility might be worth study.

7 UTILIZATION AND DISPOSAL OF WOOD RESIDUES

7.1 General

This section provides a review of the alternatives available for disposal of wood residues. A brief description of combustion and thermal degradation systems is provided to give an overview of conventional systems and some new technology. Details of seven systems are presented in a later section.

Since British Columbia produces the majority of lumber and plywood in Canada, wood residue surpluses may be greater there than in other parts of the country. Although the distribution of wood processing facilities which generate a surplus may be unique, this situation serves to illustrate the wood residue disposal problem and provides information on alternatives for disposal.

7.2 Land Disposal

Approximately 4.4 million units of wood residue are surplus and represent a disposal problem. The bulk of this surplus exists in the Interior. Recent air pollution constraints on incineration by open burning and by existing teepee burners have forced alternative disposal in landfills. Disposal by landfilling is outside the 'useful energy' aspect of this report. A brief discussion is necessary, however, to illustrate the need for utilization or disposal by thermal processes. While some on-site landfilling has been used, such as in log sorting yards, most landfills will be off site. Large volumes of hogged wood and bark are disposed of in landfills, and some is used in engineering fills such as underfill in bog land or as a temporary cover for municipal sanitary fills. All landfills are subject to provincial pollution control regulations requiring layering, compaction and periodic soil cover. Minimizing groundwater leaching is also a major pollution control requirement. Toxicity of hogged wood, sawdust and bark leachate is not clearly understood. There is indirect evidence that the leachate can be toxic to fish. Little is known about the long-term durability of wood and bark. Also, the potential for spontaneous combustion presents a fire hazard. Acceptable landfill sites are frequently not available within an 30-40 mile trucking distance and it is economically impractical to haul further for landfilling.

Surplus wood residues occur for various reasons. When strikes or poor markets curtail pulp mill operation vast hog fuel surpluses must be disposed of in landfills. Integrated sawmill-pulp mill

operations are usually in balance; residue from the sawmill being consumed by the pulp mill, and incinerators are not usually installed. However, in some cases this balance does not exist. In one instance, 500 000 units of hog fuel were available annually but only 235 000 units were required for the pulp mill boiler. The remaining 265 000 units/year were disposed of by landfilling at a cost of about \$3.75/unit. This represented a disposal cost of about \$1 000 000/year. In the spring of 1974, a modified conical incinerator, 82.5 feet high, was installed. This facility can dispose of 14.3 units/h (343 units/24 h) and costs \$250 000. Further information on wood residue disposal in landfills is available in a report by Evans (4).

7.3 Thermal Decomposition

The term thermal decomposition is used to describe processes where complex organic carbon compounds, such as wood, are converted to simpler organic carbon compounds using elevated temperatures. Combustion is the thermal decomposition process in the presence of an excess of oxygen in which the carbon and hydrogen in organic compounds are completely converted to carbon dioxide and water. Gasification is a complex conversion process taking place in the presence of water with a deficiency of oxygen. The products of this degradation are carbon monoxide, hydrogen, methane and small amounts of complex breakdown products. Pyrolysis is a complex conversion process in the absence of oxygen, producing gaseous hydrocarbons and complex mixtures of volatile and oily hydrocarbons. The processes of pyrolysis, gasification and combustion all occur simultaneously in different zones of a given type of thermal decomposition unit, and desired products, such as heat and combustible gases or liquids, can be obtained by controlling equipment configuration, temperature and amount of oxygen.

A brief review of conventional and new technology for burning wood residue identifies the main components of thermal decomposition systems and indicates those which function mainly as disposal devices.

7.3.1 Sources of Residue. Wood residues come from the following major sources in the wood processing industry.

- Forest operations - slashings, branches, needles, stumps, low grade and decayed wood
- Sawmills - sawdust, bark, trimmings, split wood, shavings from planing operations, sanderdust from finishing operations
- Pulp mills - bark and trimmings from log preparation
- Plywood mills - log trim, bark, sanderdust, veneer clippings, panel trim, etc.

7.3.2 Fuel Preparation. Pretreatment of wood residues attempts to minimize variations due to moisture content, particle size, dirt and species. Upgrading results in more stable, uniform operation allowing for complete thermal decomposition and better pollution control. Important forms of pretreatment are hogging, dewatering, screening, sizing, bulk storage and blending. Hot conveyors, hot hogs and rotary driers are sometimes used to lower moisture depending on proximity of hot gases and burner requirements.

7.3.3 Combustion. The basic functions of a combustion system are to combine fuel with air at a controlled rate, maintain ignition and remove ash and gaseous products from the reaction zone. The

systems available for combustion of wood residues fall into four categories according to how these functions are performed.

Pile burning furnaces, as their name implies, burn wood residue in a deep pile. Unprepared residue is conveyed to the top of the furnace and dumped periodically on the top of the pile. Alternatively, it may be fed to the underside of the pile by hydraulic ram. Combustion air may be admitted under the pile through cast iron or water-cooled grates. Some designs do not use grates; the pile rests on a refractory floor and all combustion air is supplied above the pile as overfire air. Overfire air is necessary for combustion of gases and particles rising from the pile and for cooling combustion products to prevent damage of the refractory furnace walls. Excess air averages about 45%. Overfire air is often supplied through many small openings or tuyeres in the furnace walls. Ash is removed manually requiring periodic shutdown of the furnace. Figure 4 depicts one of the most common pile burners, the dutch oven.

The second category is thin bed furnaces. In this type of furnace residue is mechanically or pneumatically spread across the grate in a thin layer not more than two feet deep. The residue may be hogged to eliminate large pieces. The grate is often inclined or stepped permitting the residue to move down its length with ash being discharged from the lower end. Figure 5 illustrates one such configuration. A horizontal travelling grate may be used for the same purpose. Combustion air is added through the grate and above the residue bed. In some designs the residue is spread on the grate from some height. Part of the residue burns in suspension and the remainder drops to the grate where burning is completed.

Cyclone suspension burners form a third category and are typified by combustion of all or most of the wood residue in suspension. They may be used to fire conventional furnaces for the production of steam or they may fire process dryers directly. The residue must be preconditioned to yield a fine, dry product before firing. The processed residue is metered to the burner where combustion takes place in suspension in a highly turbulent environment created by the forced combustion air (Figure 6). The volumetric heat release rate is the highest of any of the wood residue combustion systems. Ash suspended in the combustion gases may be collected in the burner itself by centrifugal motion of the gases or it may be slagged and removed in a molten state.

The fourth category, fluidized bed combustors, use hot gas at a superficial velocity of about 1.5 fps, flowing upwards through a bed of fine granular material to expand the bed and convert it to a violently agitated mass with free-flowing, fluid-like properties. The fluidized bed provides rapid breakup and mixing of solids added to it as well as very high rates of heat transfer within the bed. The fluid bed combustor will burn either wet or dry wood residues containing considerable amounts of dirt. It can handle a full range of particle sizes up to 3 in. The fluidized bed frequently consists of coarse silica sand up to 6 ft deep resting on a porous plate in chambers up to 13 ft in diameter. The combustor is a vertical refractory-lined steel cylinder with a height approximately equal to the diameter. Primary gasification takes place in the fluidized bed with final combustion taking place in the space above.

7.3.4 Gasification. Carbon in organic matter, such as wood and coal, can be converted to combustible gas by two thermal degradation processes - pyrolysis and hydro-gasification. Both processes

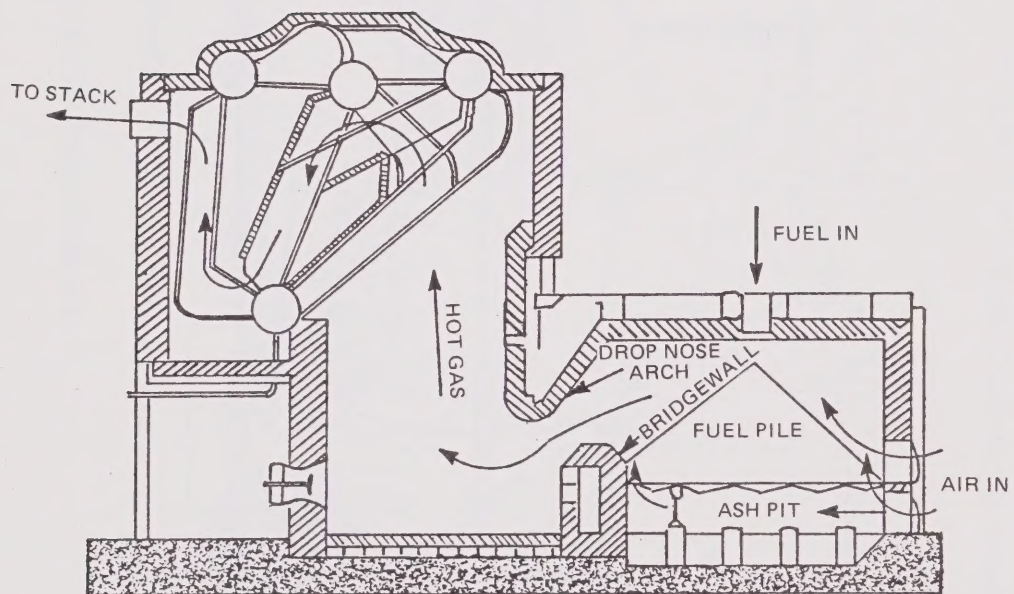


FIGURE 4 BOILER WITH A DUTCH OVEN FURNACE

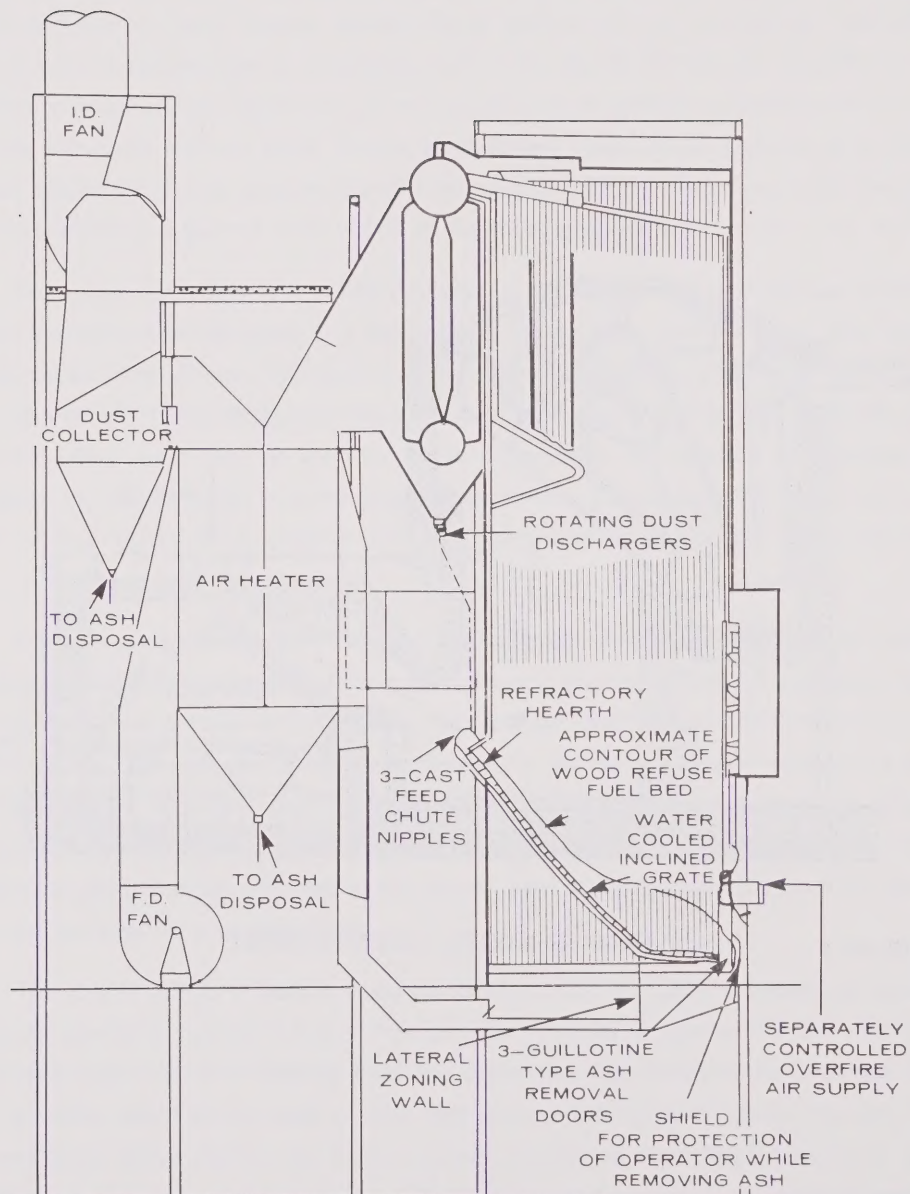


FIGURE 5 INCLINED WATER-COOLED GRATE BOILER
(FOSTER WHEELER, LIMITED)

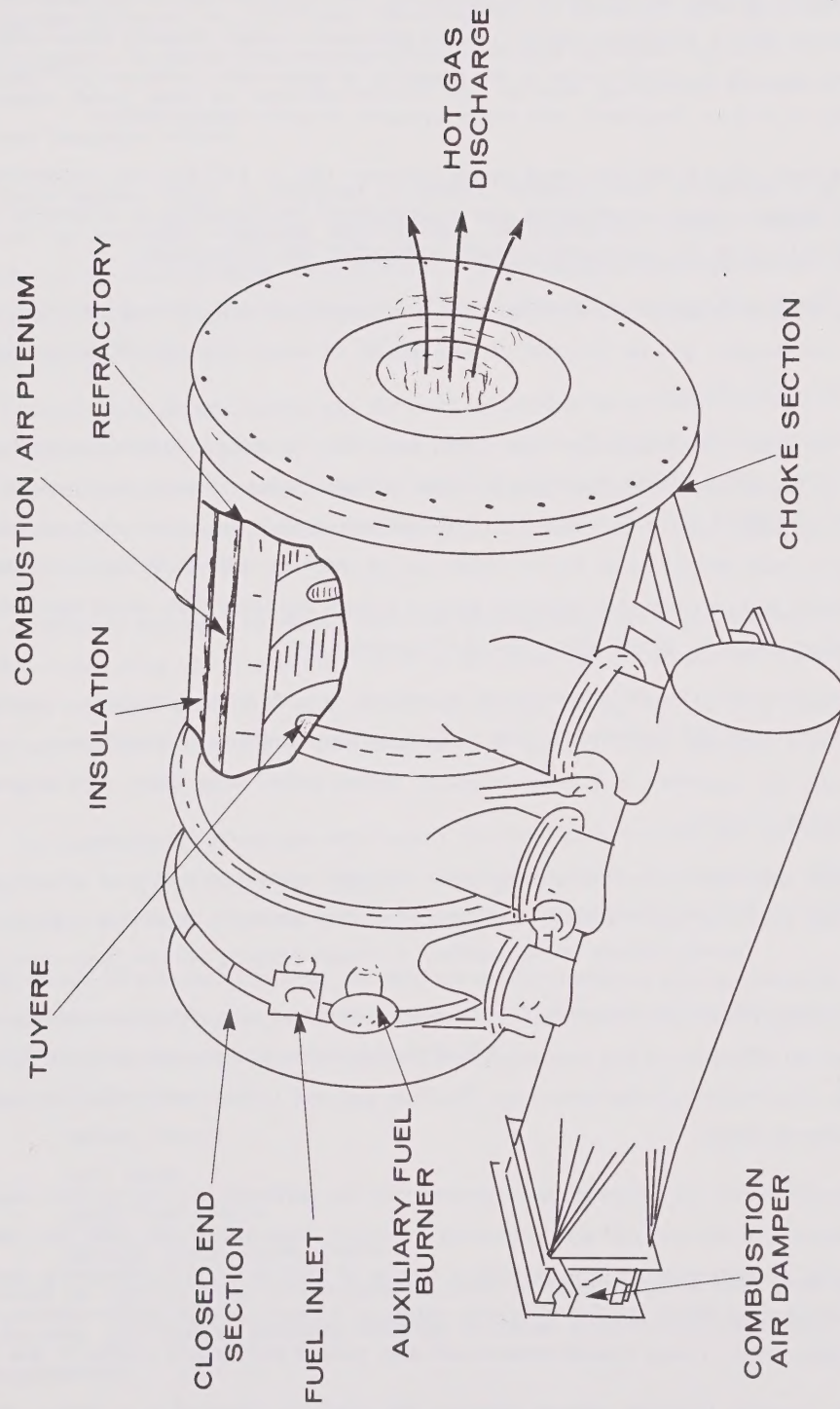


FIGURE 6 CYCLONE SUSPENSION BURNER (ENERGEX, LIMITED)

usually take place in the same reactor in a series of complex reactions. Separate reactors are also used.

Products depend on the reaction conditions. The pyrolysis step in the absence of oxygen at temperatures above 900° F produces carbon, carbon monoxide, carbon dioxide, water and a mixture of hydrocarbons and tars. Hydro-gasification in the presence of water and a deficiency of oxygen produces carbon monoxide, hydrogen, methane, and minor amounts of other hydrocarbons.

The heat value of the gas produced is between 180 to 450 Btu/scf. depending on process conditions. The relatively clean combustible gas is piped from the generator to a furnace where it may be burned for direct use of hot combustion gases or flared to the atmosphere.

7.3.5 Hot Gas Utilization. The previous section summarized conventional and new technology for generating hot combustion gas by thermal decomposition of wood residues. This section summarizes methods for utilizing this heat.

In the past, wood residues have been burned in a variety of furnaces to heat boilers to produce steam for power generation and process heat. In recent years, the development of new burners for wood (and other solid fuels) that allow relatively complete combustion and produce relatively clean, hot gases has increased opportunities for the direct use of this heat source. In fact, in some areas, such as the Interior, there is a considerable potential surplus of heat available from wood residues, and a need to develop inventive ways for direct utilization of this surplus heat.

7.3.5.1 Indirect use of hot gases. Utilization of the heat from wood residue combustion often involves steam as a working fluid. Energy is recovered from the steam in turbines or process heat exchangers. Corder (2) describes conventional power boilers which have been used to generate steam in the primary forest industry.

Boiler selection depends, among other things, on the quantity of steam required, the quantity of residue available and the desired degree of control over the steam generation rate.

In situations where available residue exceeds the amount necessary for steam generation and precise control of steam flow rate is not required, pile burning furnaces such as the dutch oven are usually satisfactory. Thermal efficiency of pile burning is low because of high excess air (about 45%). Steam flow is erratic due to intermittent residue charging. The flue gas will be relatively clean because the fuel is burned in a quiescent state.

Improvements in efficiency and control can be achieved by drying the residue to 35% moisture, screening it to remove dirt and providing a uniform feed rate to the pile. Dry residue such as sanderdust may be burned separately to provide a source of heat to dry the remaining residue before it is fed to the furnace. Removing residue moisture results in a more uniform gas temperature and thus a more constant steam rate. These improvements will also reduce particulate matter in the flue gas.

Pile burning furnaces cannot provide the response necessary to follow steam demand fluctuations. Auxiliary fuel may be incorporated to increase flexibility of the system, or a thin bed burning system employing an inclined grate can be used to effect better control of steam output. With a thin bed

system, efficiency can be improved by operating with less excess air (about 30%) and by hogging and drying the residue. The movement of the burning residue across the grate will increase particulate emissions over those from pile burning furnaces.

Further increases in control and efficiency can be achieved with spreader-stoker firing to fixed or traveling grates. Excess air may average about 25% and response to process demand is relatively rapid. Suspension firing used in spreader-stokers will increase particulate emissions over the mass burning systems discussed above.

Each system offers an increase in control flexibility and efficiency. The need for these increases must be carefully assessed against mill requirements because each improvement is accompanied by an increase in system complexity. In many cases residue generation exceeds demand and increases in thermal efficiency, achieved by using a more advanced system, result in more residue requiring disposal by other means.

Conventional steam boilers may be fired by cyclone suspension burners. This arrangement operates with excess air levels as low as 10% and with a very high degree of response to steam demand fluctuations. Particulate emissions are among the lowest of any wood-fired system. These systems require the greatest amount of residue processing; pulverization and drying to 10% moisture. Combustion gases are bled from the boiler to dry the residue.

A different approach to raising steam employs gasification of the residue in fluid or fixed bed gasifiers. A low-heat-value gas is produced (125 to 250 Btu/scf) which can be burned in conventional gas-fired boilers or piped short distances to directly fire process dryers. The gas can be stored and supplied as required. This feature eliminates the need to store the residue and vary its feed rate according to steam demand.

The gasification system can also supply fuel for a conventional gas turbine used to generate electric power or it can be integrated into the gas turbine cycle by operating under pressure and exhausting through a turbine. A waste heat boiler added to handle the turbine exhaust would increase thermal efficiency and provide process steam in addition to the electric power.

7.3.5.2 *Direct use of hot gas.* Hot combustion gas and low calorie fuel gas produced from thermal degradation of wood residue can be used to directly fire:

- lumber dry kilns
- veneer dryers
- lime kilns
- wood fuel dryers
- particle board finish dryers.

The gases must be relatively free of particulate matter for these applications. Systems using cyclonic suspension burners, pile burning multiple-chamber furnaces, fluidized bed combustors, or gasifiers can meet this requirement.

7.3.6 *Air Pollution Control.* While wood residue contains traces of sulphur, the major emission from a wood-fired facility is particulate matter. Particulate matter consists of both combustible and

incombustible material. The combustible material includes fly carbon and smoke while the incombustible material includes dirt, ash and, in some cases, sodium chloride.

The cost effectiveness of emission control is discussed by Babcock and Nagda (5). Damage to various types of materials attributed to particulate matter in the air has been estimated for the United States as follows:

	Cost/year (\$)
Residential property	3 143 000 000
Materials	2 152 000 000
Health	3 663 000 000
Vegetation	54 000 000
	9 012 000 000

This estimate of damage was due to 28.3 million tons/year of particulate matter weighted by a severity factor. From these data, an overall cost of damage due to particulate matter in air is estimated to be about sixteen cents per pound.

Particulate matter is removed from combustion gases by gas cleaning devices with efficiencies varying with particle size. Typical efficiencies on ordinary material of uniform composition when operating under optimum conditions are listed in Table 16.

While wet scrubbers can provide high efficiency removal, they require a large amount of power to operate and present a water slurry disposal problem. More development is needed for application to hog fuel-fired equipment.

A recent installation is claimed to operate satisfactorily at a pressure drop of about 14 inches of water. An electrostatic precipitator has been tested with some success on a power boiler fired with hog fuel containing salt. It was apparent, however, that close control of the electrostatic system was needed for optimum results. The multiple cyclone is the common gas cleaner on hog fuel-fired boilers in British Columbia. The forest industry has concluded that no proven commercial equipment is available for the removal of fine ash and salt fume from hog fuel-fired boilers to meet provincial Pollution Control Branch criteria. Indeed, the industry is concerned that secondary collectors may not represent the most desirable means for controlling these emissions.

The current trend is to pretreat wood residues and optimize combustion conditions. Lowering wood residue moisture content decreases the gas velocity in combustion chambers, the volume of combustion gas, and, hence, the size of gas cleaning equipment. Sizing wood particles allows more complete combustion and less fly carbon.

New dry bed scrubbers are in operation on wood-fired furnaces and have provided low particulate emissions. The newer cyclone suspension burners completely burn fly carbon making reinjection unnecessary.

TABLE 16 EFFICIENCY OF PARTICULATE MATTER REMOVAL TECHNIQUES

Method	Particle size (microns)	Efficiency (%)
Mechanical (cyclonic)	20	97
	10	90
	5	65
	2	30
Electrostatic precipitation	20	95 +
	5	90 +
	1	75
Fabric filter	0.01 and larger	99 +
High energy scrubber	5	99 +
	2	97
	1	90
	0.4	70

Instead of collecting and reinjecting fly carbon *and* ash, wood can now be burnt completely in the new cyclone suspension burners. New dry bed scrubbers are in operation on wood-fired furnaces and have provided low particulate emissions.

Salt in hog fuel from seawater-floated logs is discharged from combustion chambers as submicron particles that pass through most gas cleaning equipment. This is one of the main causes of persistent plumes and satisfactory technology to remove salt from exhaust gases has not yet been developed, although some cyclone suspension burners operate at temperatures high enough to produce a slag which may be removed from the system at the burner. New commercial installations operating in this mode were just planning start-up operations in late fall of 1974; consequently, it cannot be said that this slagging is proven or demonstrated. Hog fuel from seawater-floated logs has not yet been burnt in these slagging-mode suspension burners.

7.4 Products

7.4.1 Wood Chips. Wood residue sold to pulp mills include wood chips, sawdust and shavings. The price of these commodities fluctuates considerably according to demand and according to government controls on the market. The Province of British Columbia has recently passed legislation allowing them to set the price that pulp mills will pay for wood chips.

In mid-January 1975, the price for wood chips in the Interior, for species other than cedar, was \$35/dry ton, the price for cedar chips \$31/dry ton. The price was up from approximately \$18/dry ton immediately prior to the enactment of legislation. The price of chips on the coastal market, which is not government regulated, is approximately \$45/dry ton. Sawdust and shavings are in strong demand in the coastal market and the price is usually lower than the price for chips.

7.4.2 Charcoal. Wood charcoal is made by thermal decomposition of wood in an oxygen deficient atmosphere. Combustible gas is also produced. In local situations where demand for heat is limited, surplus energy otherwise dumped to atmosphere may be preserved by storage in a more compact form such as charcoal.

Most of the wood charcoal produced in Canada is sold in briquette form and primarily used for barbecuing. Only in recent years has Canadian production evolved to a substantial industry. Export of charcoal to the United States and Europe started in 1971 and is expected to reach 15 000 tons by 1975. Domestic shipments in 1973 totalled 33 900 tons and domestic consumption was 48 335 tons with 19 578 tons being consumed in western Canada. Imports, mainly from the United States, were 14 435 tons valued at \$1 634 000 (five and a half cents per lb). Domestic shipments in 1975 are expected to rise about 21% to 41 000 tons and domestic consumption is expected to grow to 54 300 tons with imports dropping to about 13 300 tons. The bulk of this growth in Canadian consumption is expected in Ontario and Quebec. About 65% of retail sales occur in food chain stores. In Vancouver, in June 1974, charcoal briquettes from St. Louis, Missouri, were selling at eleven cents per pound.

Charcoal deliveries start in March and end in September. Assuming a 20% yield of charcoal from wood, 54 300 tons of charcoal would utilize 271 500 tons of dry wood residue or about 271 500 units in a six-month period. This is about 30% of the surplus wood residue on the British Columbia coast or about 8% of the surplus in the Interior (See Table 15).

The advent of a continuous fluidized bed gasifier and charcoal production unit will allow large-scale production; however, charcoal production as an effective means of utilization and disposal of surplus wood residue would require an expanding export market.

By modifying operating conditions of the fluidized bed reactor, activated carbon can be produced. This product is widely used in waste water treatment and other purification processes and constitutes an additional market for wood-based charcoal. However, technology to achieve such production is in the early stages of development.

7.4.3 Synthetic Fireplace Logs. Similar raw materials are used for the production of wood charcoal and synthetic fireplace logs. Since these logs are used mainly between September and March, when demand for charcoal briquettes is minimal, the manufacture of both products would allow year-round production.

There are two basic types of logs made from sawdust and wood shavings: wood-wax logs and compressed dry wood. Most of the synthetic logs produced in Canada are the compressed dry wood-type. Imports from the United States which supply about 65% of the market are of the wood-wax type.

A unique process has been developed at B.C. Research which produces fire logs directly from wet sawdust and other similar wood residue.

By definition, one wood-wax log or six compressed-type logs equals one firelog 'unit'. Apparent domestic consumption in 1973 was 4 087 000 units valued at \$2 063 000. Domestic shipments amounted to an estimated 1 435 000 units valued at \$718 000 (fifty cents per unit) while imports from the United States were 2 652 000 units valued at \$1 345 000 (fifty-one cents per unit). The bulk of the growth in consumption of fire logs between 1971 and 1973 was in Ontario and about 65% of all retail sales occur in food store chains. In Vancouver, in June 1974, one wood-wax log (6.5 lb, 90 000 Btu/log) retailed at eighty-nine cents, and one box of compressed-type logs (45 lb) retailed for eighty-nine cents.

Assuming 10% moisture in compressed fire logs, one 'unit' would weigh about 40 lb. The 1973 Canadian consumption of 4 087 000 units is equivalent to about 163 500 000 lb of dry wood or 81 750 tons of dry wood (about 81 750 units of hogged wood residue). For synthetic fire logs to be an effective means of utilization and disposal of surplus wood residue, extensive export markets would have to be developed.

7.4.4 Other Products. While this report is limited to consideration of energy aspects for the disposal of wood residues, some other products are mentioned for the sake of completeness.

7.4.4.1 Bark board. Considerable work is going on to develop an acceptable particle board from bark; for example, hot press bark board where naturally occurring extractives are heat treated to act as binder, and high strength to weight particle board made by orienting fibres in a single axial direction in an electric field. This topic is of considerable magnitude and is not within the scope of this study.

7.4.4.2 Bark mulches. Bark residues are available unprocessed or sized to chunks (1-1/2 to 3-1/2 in.), nuggets (3/4 to 1-1/2 in.), minichips (1/4 to 3/4 in.) or mulch (below 1/4 in.). Process bark is gaining popularity as bedding material for poultry and dairy cattle and as mulch in orchards, nurseries and residential gardens. A very large market is developing in the United States for plant mulch to be used along newly constructed highways. Prices range from \$4.00 to \$7.50/ton. It has been estimated that in 1969, bark sold for soil use in the United States was about 350 000 units (200 ft³ each) and that the market is expanding.

7.4.4.3 Extractives from bark. A new \$3.2 million solvent-extraction plant for Douglas Fir bark has been built by Bohemia Incorporated at Eugene, Oregon. This full-scale installation will initially convert about 2000 tons (dry basis) of bark into vegetable wax, thermosetting resin extenders and a phenol substitute. Monthly production is estimated at 70-80 tons of wax, 1700-1800 tons of extender and 200 tons of phenol substitute. Ultimately, products will include 600 tons of cork and 500 tons of bast fibre (with corresponding decrease in extender output). Annually, this facility will consume about 24 000 tons of bark. Although this type of facility upgrades the products available from bark, it cannot be considered a major consumer of the large quantities of bark residue available.

8 THERMAL DECOMPOSITION SYSTEMS FOR ON-SITE DISPOSAL OF WOOD RESIDUES

8.1 General

In the previous section five processes were identified for the thermal degradation of wood residues. In this section, one system from each of the five categories is described to provide information on features, function of components, operation, air pollution potential, costs, advantages and disadvantages. The systems discussed are not to be considered as preferred. They were selected as typical of the categories and because performance data was available from actual operation.

8.2 Modified Conical Incinerators

8.2.1 Features. The modified conical incinerator is an evolution of the original enclosed pile burner generally called a conventional teepee (or wigwam) burner. Conventional teepee burners exist in many varieties and forms with almost all employing underfire and secondary air. These burners were frequently abused and poorly operated. A modified conical incinerator is differentiated from a conventional teepee burner by being an integrated unit designed to allow automatic control of the fuel feed rate, air supply and exhaust gas temperature.

The incinerator can dispose of wood residues of varying moisture content and various particle sizes. Recent designs feature automatic control so that little input is required from sawmill personnel. Modified conical incinerators, such as the 'Burn-o-matic' manufactured by Lamb-Cargate Industries Limited are available in sizes which dispose of 1.5 - 15 units/h. The burners have a turndown ratio of 1.5:1. The exhaust gases are generally not suitable for use in the mill although a few mills have attempted to utilize waste heat with some success.

The modified conical incinerator such as the 'Burn-o-matic' will generally consist of:

- a structurally sound leakproof shell
- temperature sensors in the combustion chamber and near the exhaust gas exit
- an automatic control system
- forced air system
- automatically controlled dome damper
- inner liner to protect the external shell
- an optional auxiliary firing system.

Figure 7 is a cross-sectional diagram of a typical modified conical incinerator. Figure 8 shows a modified conical incinerator in operation.

8.2.2 Functions of Components

8.2.2.1 Shell. The structurally sound, leakproof shell eliminates the natural draft, overfire air effect common to conventional teepee burners. The natural draft system on conventional teepee burners can supply more than 400% excess air, which lowers the exit temperature of the burner and increases the amount of smoke and flyash.

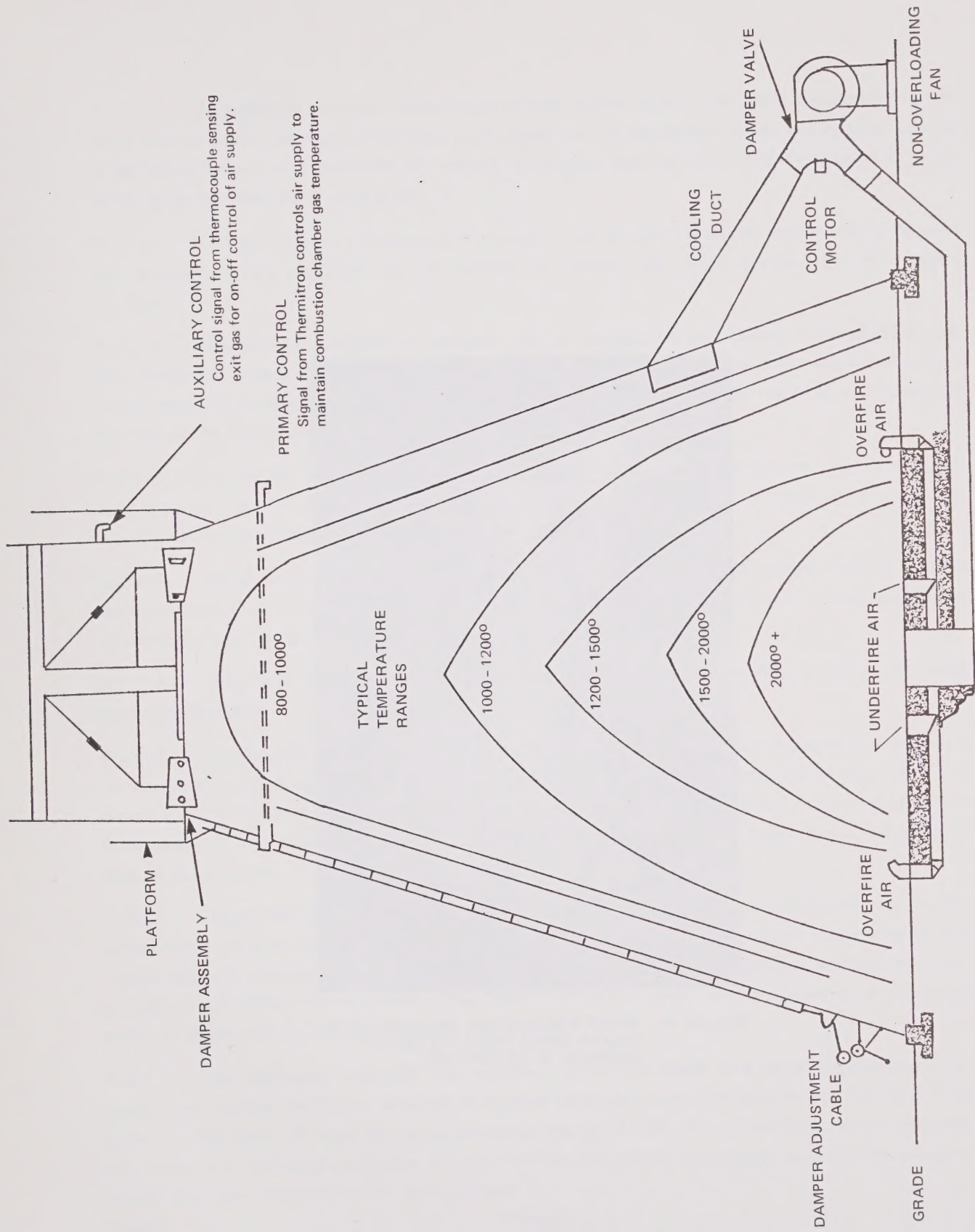


FIGURE 7 MODIFIED CONICAL INCINERATOR (LAMB-CARGATE)

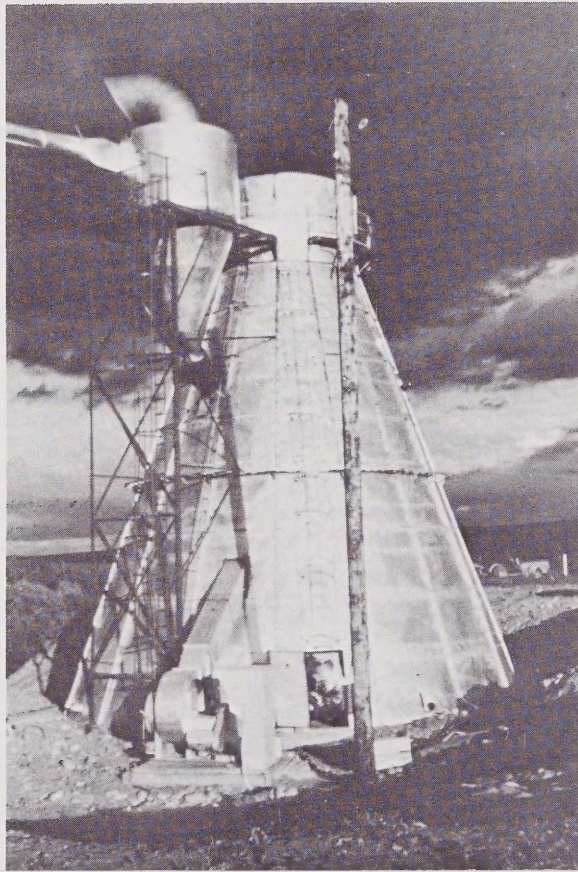


FIGURE 8 MODIFIED CONICAL INCINERATOR.
(DOOR OPEN ONLY TO SHOW
BURNER IS OPERATING)

8.2.2.2 Temperature sensors. Temperature sensors are the heart of the automatic control system. Stack sensors supply feedback information to the automatic control system, which controls the position of the dome damper, and modulates the amount of underfire and overfire air and the amount of air fed to the space between the double walls.

8.2.2.3 Control systems. A Honeywell 'Thermitron' control system monitors and records combustion gas temperature and regulates the combustion air system, the dome damper and the residue conveyor.

8.2.2.4 Overfire and underfire air systems. Air for combustion and cooling is supplied by one non-overloading blower designed to give a high air volume to horse power ratio. A diverter valve, located in the blower airstream, is actuated by the control system and reacts to the needs of the incinerator diverting air for either combustion or cooling of the shell.

8.2.2.5 Forced air nozzles. Underfire air is supplied through a number of low velocity grates in the base of the burner. Overfire air is supplied through a series of aligned nozzles designed to control the internal turbulence of the burner.

8.2.2.6 Dome damper. An automatic dome damper connected to the 'Thermitron' system controls the exit temperature of the combustion gases. When the exit temperature is low it inhibits gas release retaining the heat in the burner.

8.2.2.7 Inner liner. Air flow between the walls provides insulation and cooling, protecting the walls from excessive heat.

8.2.2.8 Auxiliary firing system. The auxiliary firing system minimizes start-up time and maintains the temperature inside the incinerator. The system may use natural gas, propane, oil or sanderdust and directs a 3000° F flame towards the waste pile. It is used when pollution control requirements call for rapid start-up and constant operation throughout the day. It can also assist the combustion of hard-to-burn wastes.

8.2.3 Operation. The 'Burn-o-matic' consumes waste products by means of a forced overfire draft system which creates a cyclonic motion above the burning waste. Underfire air is forced through low velocity grates to break up and expose unburned materials. The amount of air supplied is closely regulated so that exhaust temperatures remain in the 700° F to 900° F range. Exit temperatures in this range minimize smoke and fly-ash temperatures above 700° F.

8.2.4 Air Pollution Potential. The modified conical incinerator is a major improvement over conventional teepee burners in reducing particulate emissions. A conventional teepee can emit 1.00 grains per standard cubic foot (gr/scf) of particulate matter at 12% CO₂. A modified conical incinerator can, under ideal operating conditions, emit less than 0.100 gr/scf of particulate material. The following results have been reported for the 'Burn-o-matic'.

Agency	Result
Olympic Air Pollution Control Authority	0.0585 gr/scf corrected to 7% oxygen (approx. equivalent to 12% CO ₂)

Kentucky Air Pollution Control Commission	0.096 gr/scf corrected to 12% CO ₂
British Columbia Pollution Control Branch ¹	0.066 gr/scf corrected to 12% CO ₂ (ideal operating conditions)
	0.144 gr/scf at 12% CO ₂ (average over 2 days of tests)

8.2.5 Costs. Costs for a 'Burn-o-matic' incinerator are listed in Table 17.

TABLE 17 BASE COSTS FOR 'BURN-O-MATIC' INCINERATOR, JULY 1974

Size (height) (ft)	Capacity (units/h)	Tons dry wood per 8-h day (assume 2000 lb/unit)	Cost* (\$)
40	1.6	12.8	33 000
60	5.5	44.0	60 000
67.5	7.8	62.8	68 000
75	10.7	85.6	82 000
82.5	14.3	114.4	104 000

*Taxes, delivery, installation and other costs could add 50% to base burner costs depending on installation and location.

Operating costs for a large conical incinerator could be as high as \$25 000/year, one-third being for electricity for blowers and motors, the remainder for maintenance. For optimum operation, the incinerator requires thorough cleaning once per week. Most mills tie this in with regular weekend clean-up so that exact costs are difficult to obtain but 30 to 40 man-hours per week is a reasonable estimate.

8.2.6 Advantages and Disadvantages. The modified conical incinerator has several advantages over other proposed alternatives to the conventional teepee burner. It is able to dispose of residues with varying moisture content as well as unhogged wood residue. Maximum moisture content is that which will support combustion and maximum size of wood residue is that which can be transported into the burner. When moisture content exceeds about 180% dry basis (64% wet basis), it is difficult to maintain a stable flame.

¹Non-isokinetic sampling; incinerator required adjustment by manufacturer. Burner is reportedly operating better since adjustments.

Modified conical incinerators are usually reliable. The automatic control systems are very sensitive, however, and since they are subjected to a harsh working environment some mills have experienced failures. Failure of the automatic control system could cause the burner to smoke, producing excess flyash or overheating and buckling of the burner shell.

A major disadvantage of the modified conical incinerator is its apparent similarity to the conventional teepee burner. There is a great deal of misinformation on operation of teepee burners which is carried over to the modified conical incinerator because of their similar appearance. The incinerator is sensitive to feed rates. The automatic control system can tolerate only a 10% increase and 30% decrease on the rated burner capacity. This factor can be particularly troublesome during winter operation when mill production usually drops off due to cold temperatures.

8.2.7 *Comparable Equipment Offering Variations in Design.* In addition to the 'Burn-o-matic' (manufactured by Lamb-Cargate Industries, Limited) modified conical incinerators are manufactured by:

Rees-Medford, Inc.

J. S. Lausmann Corp.

Central Interior Steel Fabricators, Ltd.

Applied Pollution Control, Ltd.

8.3 Pit Incinerators

8.3.1 *Features.* The open-pit incinerator was originally developed by Du Pont to dispose of materials which presented an explosion hazard when burned in conventional closed incinerators. These incinerators have since been adapted to burn a variety of wastes including wood residues. Pit incinerators, such as those manufactured by Consumat Systems, Incorporated are available in sizes ranging from 1.5 to 10 units/h and can dispose of wood residues of any moisture content and almost any size.

The incinerator has a forced air manifold which creates a rolling action of high velocity air over the burning pit. Very high burning rates and long residence times are achieved leading to complete combustion and high flame temperatures. The amount of air delivered to the fire is manually controlled as is the feed rate.

The open-pit incinerator currently has no provision for utilizing waste heat. Some manufacturers are adding an enclosure over the pit on permanent models which may allow waste heat utilization. Figure 9 is a diagram of a pit incinerator and Figure 10 shows a mobile air curtain supply.

8.3.2 *Functions of Components*

8.3.2.1 *The pit.* Empirical and theoretical calculations indicate the optimum pit width to be 8 ft. The system's capacity is determined by the pit length (between 8 and 56 ft). The pit is 10 to 12 ft deep with some provision for ash clean-out. Five hundred pounds of wood residue per hour can be incinerated per foot of trench length.

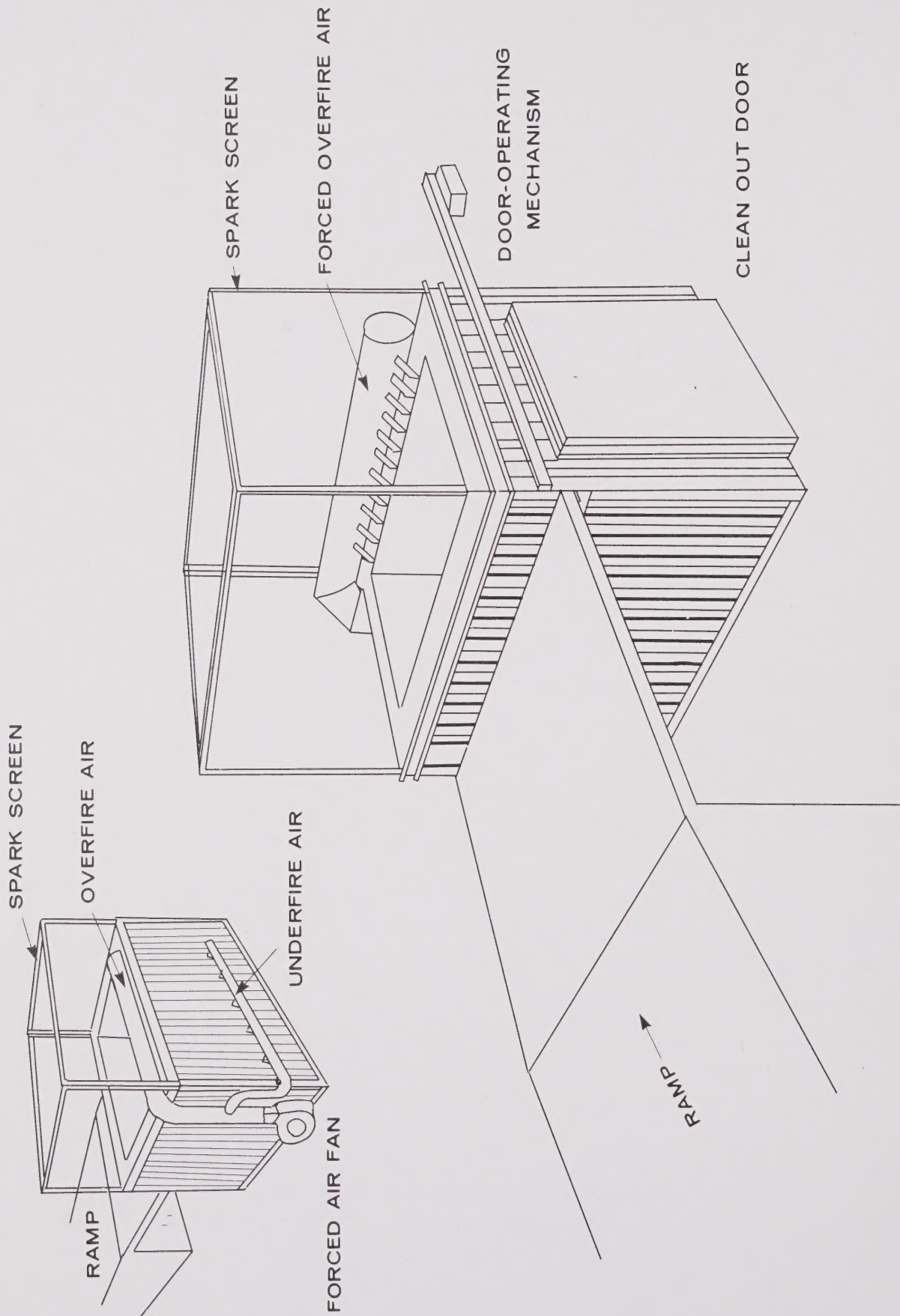


FIGURE 9 OPEN PIT INCINERATOR (PLIBRICO CANADA, LIMITED)

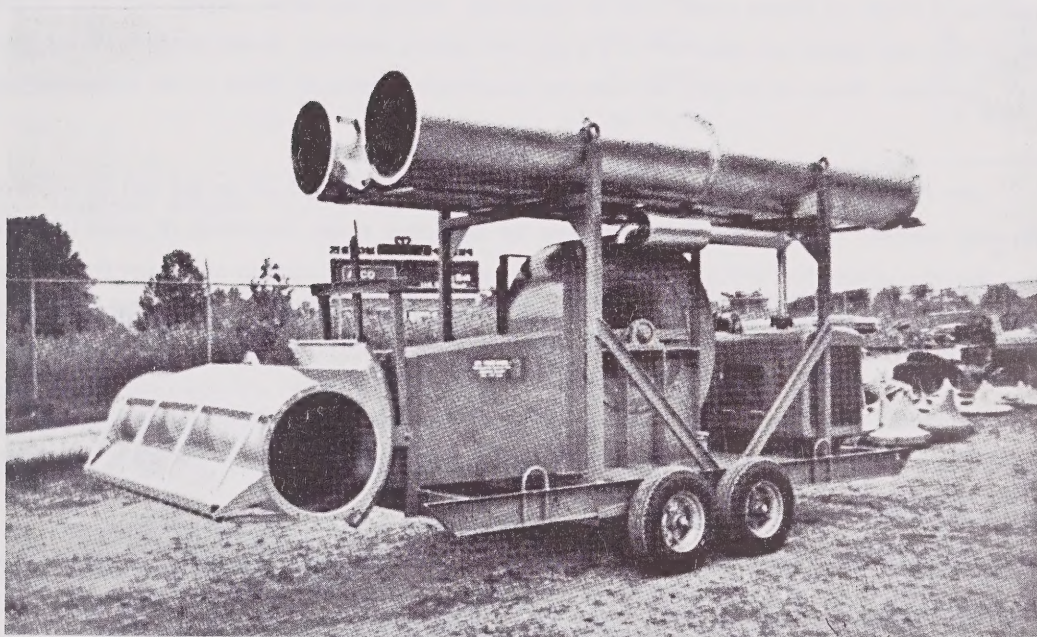


FIGURE 10 PORTABLE AIR CURTAIN SUPPLY FOR PIT INCINERATORS UP TO 56 FEET LONG

8.3.2.2 Overfire air manifold. Overfire air is supplied by a manifold running along one edge of the pit. Air is introduced through a series of nozzles, which direct the air downward at an angle of 25 to 35 degrees across the incinerator. Overfire air is supplied at 850 ft³/min/ft of trench length at a static pressure of 12 inches of water.

8.3.3 Operation. Temporary installations usually drop the wastes into the fire with a clam shell-type loader. Permanent installations have a loading ramp on the side of the pit opposite the air manifold and fuel is pushed into the pit by a bulldozer.

High velocity air from the overfire air manifold creates a turbulent burning zone, and excess air supplied at a rate of 300% aids complete combustion. When equipment is operated properly, the air pattern creates a sheet of flame under the air manifold, rolling the flame across the top of the pit. Particulate matter and gases are returned to the pit, and smoke intensity rarely exceeds Ringelmann 1. Satisfactory operation depends largely on operator experience, because there is no automatic control system.

8.3.4 Air Pollution Potential. Particulate emissions of less than 0.25 gr/scf can be achieved for most industrial wastes. Higher concentrations can be expected when disposing of materials such as sawdust or shavings since the particles are too light to penetrate the air curtain and enter the combustion zone. These particles, although too light to penetrate the air curtain, fall out of the air within a radius of 200 ft from the pit.

Emission data from pit incinerators are scarce because the geometry of the incinerator does not lend itself to conventional monitoring methods. Most emission data are in the form of ambient air sampling in the vicinity of the pit.

The British Columbia Pollution Control Branch is hesitant to issue pollution control permits for pit incinerators disposing of wood residues. Their approach to date has been to suggest that the operator first obtain a letter of approval for a six month period from their Regional Office. After six month's operation, if performance has been satisfactory, a permit may be issued. The uncertainty of this approach has caused several potential users to decide against purchasing a unit.

8.3.5 Costs. Consumat Systems, Incorporated manufacture a range of pit incinerators. These portable incinerators are available either skid- or trailer-mounted. The blower on the skid-mounted model can be driven by either a diesel or an electric motor. The trailer model is available only with a diesel motor. Costs of the various models are listed in Table 18.

A permanent installation 16 ft long with refractory-lined pit, overfire and underfire air manifolds, and screen cover costs \$108 000 including installation. A 40 ft permanent installation costs \$200 000.

Operating costs for pit incinerators are relatively high because an operator and machine are required to feed the burner. Maintenance costs are very low, however, because the equipment is simple.

TABLE 18 COSTS OF VARIOUS PIT INCINERATORS MADE BY CONSUMAT SYSTEMS INCORPORATED*

Pit length (ft)	Capacity (units/h)	Cost for skid model (\$)	Cost for trailer model (\$)
16	3	22 000	25 500
24	4.5	24 000	27 500
32	6	25 000	28 000
40	7.5	27 000	30 000
56	10	28 500	31 500

*Prices obtained August 1974, fob Vancouver, Federal Sales Tax included.

8.3.6 Advantages and Disadvantages. Pit incinerators have a low capital cost and are simple to operate. They are easily made portable which makes them practical for the 75% of sawmills in British Columbia that are portable. Many of these small mills do not have a burner at present and even with its relatively high particulate emission concentration the incinerator can dispose of wastes more efficiently than the open burning which is currently practiced.

Without a top on the pit incinerator, it is not possible to collect and utilize hot gases. This is not a serious drawback as most of these portable sawmills have no need for this heat energy.

With no control system to malfunction, the pit incinerator is probably the most reliable thermal decomposition system dealt with in this report. Although designed to dispose of hazardous materials, it can safely dispose of wood residue. Wood chips and large-sized wood wastes have been burned successfully in the pit incinerator; however, successful burning of sawdust alone has not yet been established.

8.3.7 Comparable Equipment Offering Variations in Design. Several manufacturers of pit incinerators offer permanent models, equipped with an underfire air manifold, refractory-lined walls and a cover. These models have larger capacities because of the underfire air and partly-enclosed combustion chamber. These modifications, turn the unit into a single chamber incinerator. Pit incinerators are manufactured by the following suppliers:

- Closed Pit - Plibrico (Canada), Ltd.
 Consumat Systems, Inc.
- Open Pit - Trecon, Ltd.
 Consumat Systems, Inc.
- Portable Pit - Consumat Systems, Inc.

Driall, Inc. – 4 models handling up to 14 tons/h
The Camran Corporation – 'Air Curtain Combustion Unit' (ACCU) (Figure II)

- mounted on 5th wheel trailer, complete with hydraulic grapple hook for feeding combustion pit
- capacity 15 tons/h in chamber (14 x 14 x 20 ft)
- available through licencees on contract basis
- disposal costs about \$6.50/ton.

'Portapit' (Open top)

- skid-mounted with overfire air curtain supply, air-cooled refractory walls and grates with chamber at about 1200° F
- \$29 800 for model with 20 ft combustion chamber rated at 30 yd³/h (about 7.8 ton/h)
- \$42 800 for model with 27 ft combustion chamber rated at 40 yd³/h (about 10.4 ton/h).
- preliminary emission control design is completed for fixed-site units.

8.4 Multiple Chamber Incinerators

8.4.1 Features. A multiple chamber incinerator, such as that manufactured by the Automatic Combustion Division of the Michel Lumber Company, consists of a furnace cell and a number of combustion chambers. The incinerator is designed to burn wood residues with up to 60% moisture content (wet) and of any size that can be fed through an auger feed. The unit is completely automatic and requires minimal attention during operation. The incinerator has a turndown ratio of five to one. Exhaust gases from the furnace are clean enough to be used in a direct-fired dry kiln without cleaning. The largest unit can dispose of three units of fuel each hour. A schematic diagram of a multiple chamber incinerator is shown in Figure 12 and Figure 13 shows an actual installation.

8.4.2 Functions of Components

8.4.2.1 Fuel surge bin. Fuel is conveyed either pneumatically or mechanically to a surge before being admitted to the furnace cell. The surge bin eliminates fluctuations in fuel supply and allows fuel to be metered to the furnace cell according to the demand determined by the exhaust temperature.

8.4.2.2 Auger feed screen. The auger allows fuel to be fed to the furnace cell without air being admitted. It also limits the size of wood residue admitted to pieces approximately 4 in. in diameter.

8.4.2.3 Furnace cell. The furnace cell is bottle-shaped, refractory-lined, approximately 6 ft in diameter and 8 ft high, with a cast iron, water-cooled grate at the bottom. Combustion air is admitted through the grate, through the sides of the cell into the burning pile and at two levels above the pile. The ratios of the four air inlets can be altered to suit the fuel.

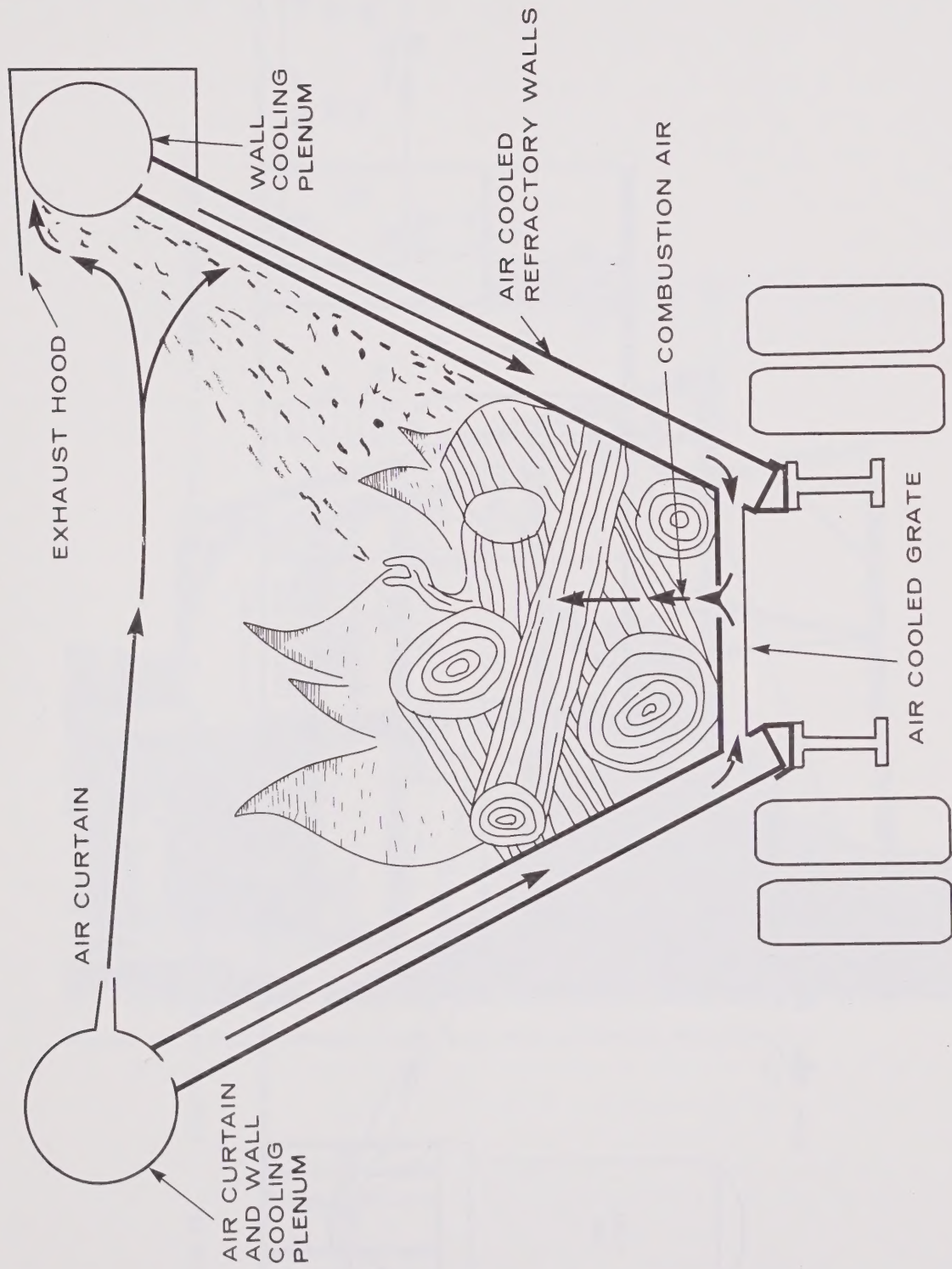


FIGURE 11 CAMRAN AIR CURTAIN COMBUSTOR

Code:  Fuel
 Hot Air and Combustion Products

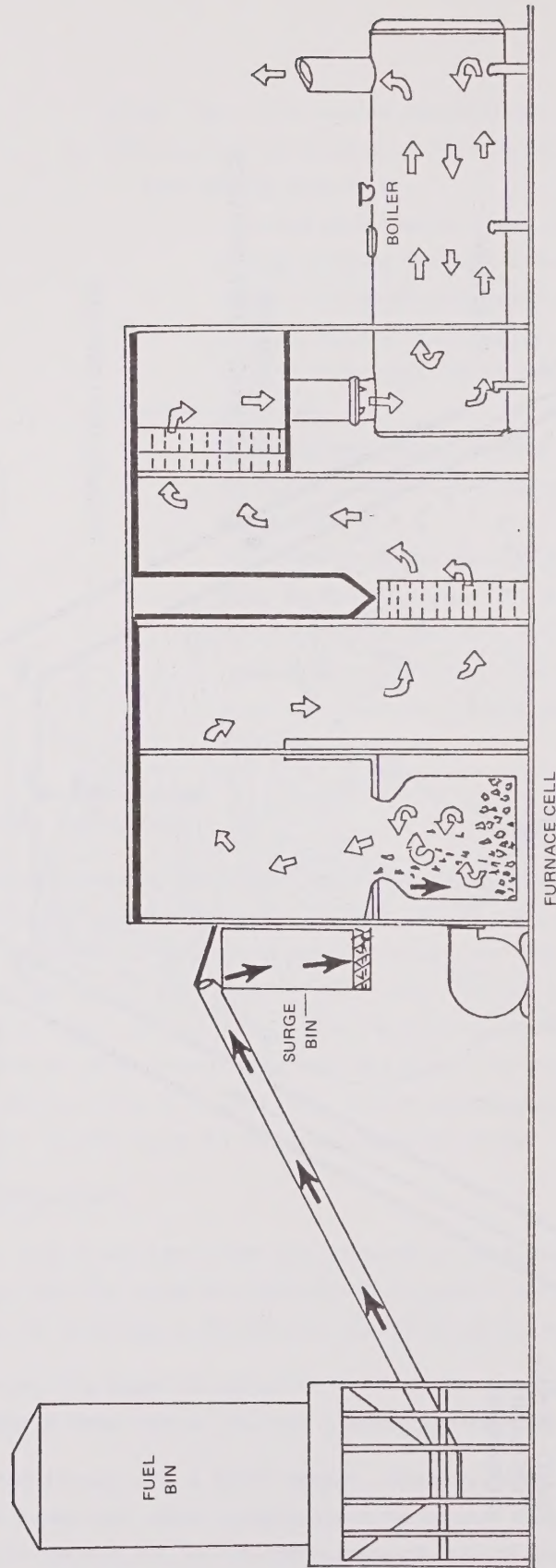


FIGURE 12 TYPICAL CROSS SECTION AND FLOW OF A MODEL '60' AUTOMATED COMBUSTION FURNACE FIRING A BOILER

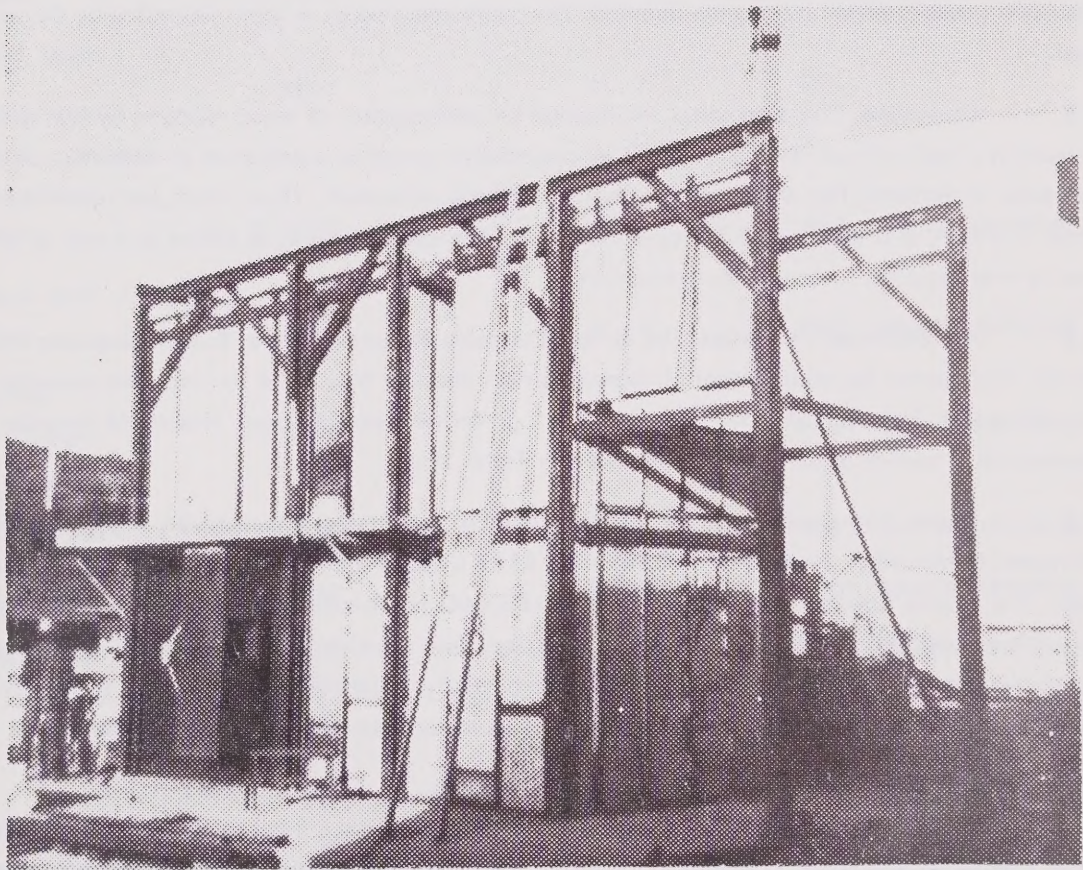


FIGURE 13 'PILE BURNING' TYPE MULTIPLE CHAMBER INCINERATOR

8.4.2.4 Combustion chamber. The combustion process, started in the furnace cell, is completed in four combustion chambers. These chambers increase the time available for combustion and, because of their geometry, also increase the turbulence of the exhaust gases.

8.4.2.5 Exhaust stack. The exhaust gases are diluted with outside air and cooled from 2000° F to a lower temperature if the heat is being utilized in some process which calls for lower temperature gas. A damper is used to modulate the amount of air added.

8.4.2.6 Automatic control system. The entire system is automated by pneumatic controls. The fuel feed rate is modulated by the temperature of the combustion gases. The required temperature of the combustion gases is preset by process demand. The combustion air is, in turn, controlled by the amount of fuel.

8.4.3 Operation. The automated combustion furnace disposes of wood residues by first gasifying the wood in a fuel-rich cell then adding the air required to complete combustion in a number of in-line combustion chambers. The entire system is automatically controlled. Three sizes are presently being offered: 2 unit/h, 2.5 unit/h and 3.3 unit/h capacity. The combustion air is added at a rate of 25% in excess of that required to complete combustion.

8.4.4 Air Pollution Potential. The British Columbia Pollution Control Branch proposes multiple chamber incinerators for replacement of teepee burners because they meet the required emission level of 0.100 gr/scf. The manufacturer guarantees 0.1 gr/scf with no collectors. Results of emission tests performed on a variety of fuels, are summarized in Table 19.

8.4.5 Costs. The capital costs for multiple chamber incinerators are relatively high. The smallest 'Automated Combustion' furnace (2 units/h) costs \$125 000 for the furnace and \$40 000 for erection labour. The largest furnace (3.3 units/h) costs \$183 000 for the furnace and \$50 000 for erection labour. These costs do not include associated and supporting services and equipment such as power to the site, freight, foundation, shelter building, automated fuel storage bin, conveyors to hog mill, or induced draft fans. The total cost for the smallest unit could easily be \$325 000 and for the largest \$400 000.

There are presently only two such furnaces in operation; a demonstration unit at the Michel Lumber Company, which has operated for over four years, and a year-old installation at an undisclosed site. Information on the recent commercial installation is not available from the owner; consequently, the true operating costs are not known. It is estimated that the power costs and routine maintenance costs will be comparable to those of a modified conical incinerator.

8.4.6 Advantages and Disadvantages. The automated combustion furnace can dispose of a wide variety of wood residues cleanly and efficiently. The furnace is not limited by moisture content of fuel other than that which will support combustion. Fuel must be hogged so that it can be transported by screw feed. The emission rate is less than 0.100 gr/scf for many different fuels. The unit does not require a full time operator. The system can be adapted to a variety of processes requiring heat, including veneer dryers, boilers, dry kilns, rotary driers, etc.

TABLE 19 PARTICULATE EMISSIONS FROM MULTIPLE CHAMBER INCINERATORS

Fuel	Emission rate (gr/scf at 12% CO ₂)	Moisture content (% wet bases)	Monitoring method
Fir bark	0.054	48.8	EPA
Fir and cedar bark	0.058	61.7	EPA
Hemlock, fir and spruce, bark + sawdust	0.043	62.9	High volume sampling
Fir bark and sawdust	0.049	51.4	High volume sampling
Papermill pond sludge	0.031	67.2	High volume sampling
Knots from paper process	0.029	64.8	High volume sampling
Alder sawdust	0.082	66.3	High volume sampling
Plywood trim	0.052	42.4	High volume sampling

Little information has been released by the owner of the only industrial installation of the automated combustion furnace; consequently, no remarks on the reliability or safety of this system can be made.

8.4.7 Comparable Equipment Offering Variations in Design. A number of manufacturers produce cyclonic chamber or 'Controlled Air' incinerators used for disposal of municipal waste which they claim will dispose of wood residue. These units are small, the largest disposing of one unit per hour. Air supplied to the fuel bed is reduced to below theoretical, minimizing entrainment of particles from the bed. Units frequently have afterburners in a secondary combustion chamber to complete the combustion process. No emission data and little operating experience are available for evaluation of their performance on wood. Cyclonic chamber-type incinerators are being used in increasing numbers in the State of Washington to dispose of wood residue in shingle and shake mills, waste from roadside clearing and municipal demolition refuse. Several units were scheduled to start operation in the fall of 1974.

Preliminary data indicate emissions of 0.05 - 0.2 gr/scf. Cyclonic chamber incinerators are supplied by the following manufacturers:

Consumat Systems, Inc.
Comtro Division, Sunbeam Equipment Corporation
Enertherm, Inc.
Pyrotherm Equipment, Ltd.
Envirometrix

8.5 Cyclone Suspension Burners

8.5.1 Features. A cyclone burner, such as the Energex 'Cyclotube', burns sized, dry wood in suspension. The moisture content of the fuel must be less than 15% (wet basis) and wood used as fuel should pass through a 1/8-in. screen. The unit is fully automatic requiring minimal attention during operation.

The incinerator was designed to utilize hot exhaust gases and has been successfully applied to dry kilns, veneer dryers, rotary dryers and other processes. Five burner sizes are offered ranging from 0.5 unit/h to 4 units/h. Energex 'cyclotube' burners have a turndown ratio of five to one.

The Energex has three main components: the fuel metering bin, the burner and the automatic control system. A schematic diagram of a cyclone burner is shown in Figure 14. A 27.5 million Btu/h installation is shown in Figure 15.

8.5.2 Functions of the Components

8.5.2.1 Fuel metering bin. Wood is conveyed to the 2-unit fuel metering bin from a larger storage bin or pile. If the raw fuel is wet and coarse it must be dried and pulverized. The metering bin feeds the prepared fuel according to a signal from the burner or from the process using the heat. The fuel is then pneumatically conveyed to the burner.

8.5.2.2 The burner. The burner is a refractory-lined tube with a square-edged choke at its outlet end. Combustion air is delivered to three separate chambers surrounding the internal refractory cylinder. Air volume is controlled by a damper on the inlet to the combustion air blower. The proportion of air to each chamber is adjusted manually to suit the fuel.

8.5.2.3 The automatic control system. The control system modulates the metering bin feed and the combustion air feed according to the temperature of the exhaust gases or some other process signal.

8.5.3 Operation. Fuel is blown into the burner and set into a cyclonic flow pattern. Combustion air is supplied from the combustion air fan, through the combustion air manifold and up three legs into three chambers located between the refractory cylinder and the outer steel casing, and then to the tuyeres. The tuyeres also admit the air in a direction tangent to the inner circumference throughout the length of the burner.

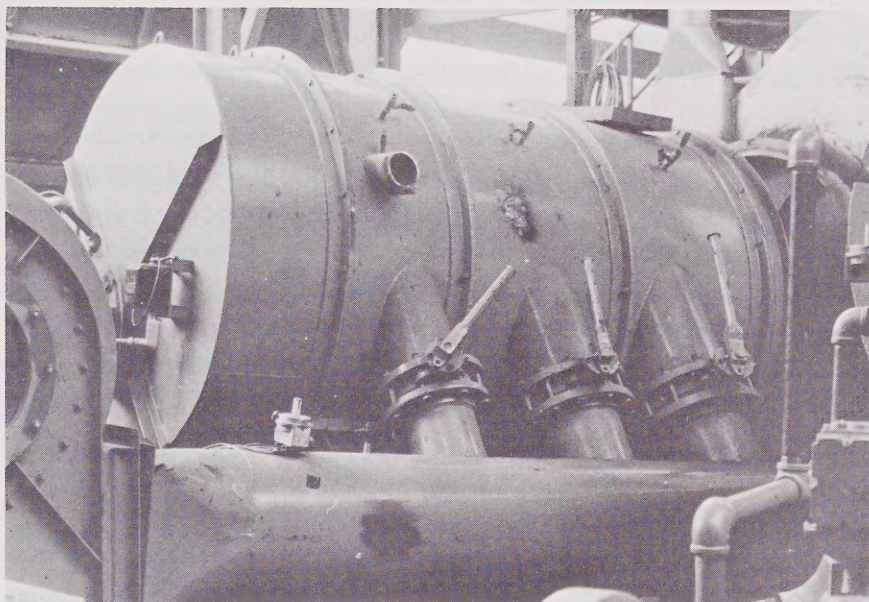


FIGURE 14 CYCLONE SUSPENSION BURNER SYSTEM
(ENERGEX, LIMITED)

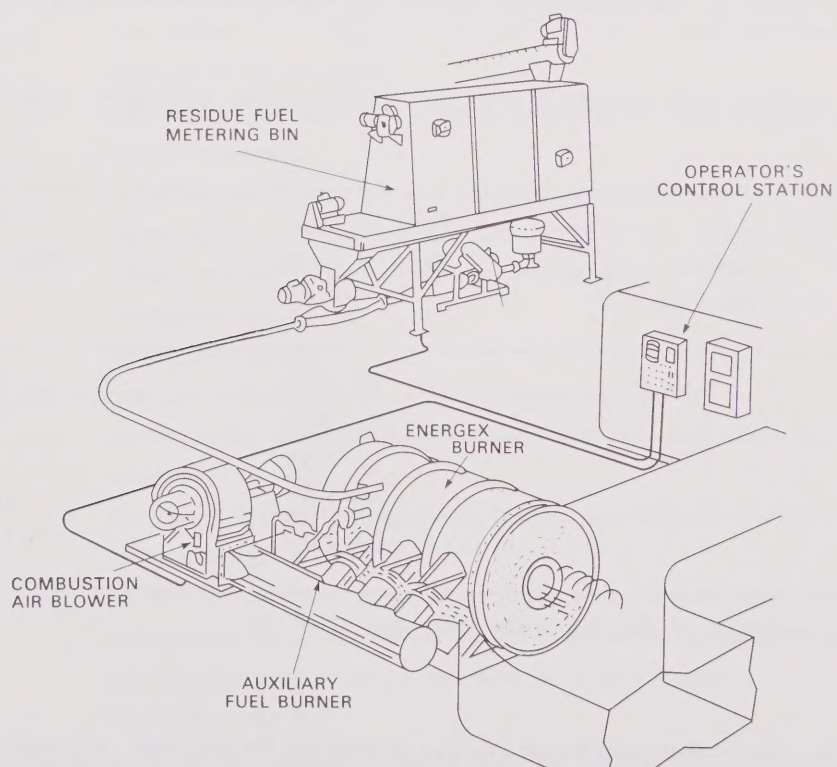


FIGURE 15 'CYCLOTUBE' CYCLONE SUSPENSION
BURNER (ENERGEX, LIMITED)

Manual control valves on the three legs allow the burner to be set for different fuels by varying the proportion of air admitted to each third of the burner. These valves are adjusted initially and locked in place once desired proportions have been achieved.

Auxiliary fuel is used only to start the Energex burner. The chamber is preheated for 15 min, then fuel and air are introduced at a low rate which is increased until the brick reaches a temperature of 900° F. At this temperature combustion is self-sustaining; the gas burner is turned off and the feed rate modulated as desired.

8.5.4 Air Pollution Potential. For use in other processes exhaust gases must be free of particulate matter. Energex offers a slagging model of their burner. This model operates at such a high temperature that ash and incombustibles melt becoming a free flowing slag which can be removed while the burner is operating. For clean fuels with a low ash content a non-slagging model is available.

One installation of a non-slagging Energex, burning sanderdust, had an emission of 0.084 gr/scf at 12% CO₂. Slagging models are designed to remove 5% of the total wood input as slag, and consequently, have less particulate emissions. Although there are many Energex burners in operation, most are used for process heating so that direct emission data are scarce.

8.5.5 Costs. Costs for the Energex burner alone are relatively low but costs for the complete system can be high. Prices for the metering bin, burner, and control system are listed in Table 20.

TABLE 20 PRICES FOR ENERGEX CYCLONE SUSPENSION BURNERS, JULY 1974*

Size (MM Btu)	Capacity (Units/h)	Price for non- slagging model (\$)	Price for slagging model (\$)
6	0.5	48 000	68 000
15	1	51 000	70 000
27.5	1.75	54 000	75 000
45	2.75	78 000	100 000
60	4	91 000	110 000

*These prices are exclusive of freight, installation and sales tax.

Auxiliary equipment costs for an Energex system can be very high. A recent installation at one of British Columbia's largest sawmills consisting of two, 27.5 million Btu/h Energex burners and a rotary kiln to dry hog fuel, cost about \$1.5 million.

Operating costs for the slagging model are relatively low. Approximately \$600/year is required to maintain the refractory which has a life expectancy of over five years. As a result of the slagging mode it is not necessary to clean the burner weekly. Operating costs for the non-slagging model are slightly higher since regular clean-out is required.

8.5.6 Advantages and Disadvantages. The Energex 'Cyclotube' and other cyclone suspension burners can dispose of dry, fine wood residue very cleanly and produce a hot, usable exhaust gas. For the disposal of all mill residues, the system can become expensive, because of the need for fuel sizing and drying equipment. Heat from the 'Cyclotube' burner can be used in a variety of mill processes such as dry kilns, space heating and veneer dryers.

There have been fires in dry kilns heated directly by cyclone burners but these fires were not caused by the direct-fired burner system. Reliability of the 'Cyclotube' burner appears to be excellent with no known failure of refractory to date.

8.5.7 Comparable Equipment Offering Variations in Design. Cyclone suspension burners, comparable to the 'Cyclotube' burner by Energex Limited are:

Combustion Equipment Associates – 'Double Vorex'

- cyclone in double-cone combustion chamber
- small diameter cone at each end of chamber
- ash collects at larger diameter in centre of chamber and is ejected through slots
- fuel metered into chamber near exhaust port, moves backward and then forward through centre of vortex
- combustion air under pressure is supplied to a wind-box surrounding the double conical chamber
- air enters outlet cone tangentially through slots and swirls along the wall towards the truncated apex of the second cone where gases reverse direction forming a tight vortex swirling through the centre to discharge
- turndown ratio 6:1
- recent development.

Mill Conversion Contractors Inc. – MCCI Suspension Burner

- system tailor-made for users requirements including rotary drier for wet hog fuel, if needed
- dry fuel metered to suspension burner operated at relatively low temperature to prevent slagging
- all hot wet exhaust gases from rotary drier, veneer drier, etc. are blended with combustion gases from wood burner to lower the temperature of blended gases and to incinerate fumes, odors and fine particulate matter
- turndown ratio 4:1

Peabody CP Burner Division – Gordon-Piatt SF Burner

- solid fuel centrifugal-fan-type burner designed to burn either solid, liquid or gaseous fuels

- may be installed on existing boilers as well as new hot gas conversion units
- requires dry, sized, clean wood from storage silo
- widely used in furniture plants to fire boilers formerly using oil or gas.

Several other cyclonic burners are made but no information is available on applications using wet or dry wood residue. Suppliers are:

Babcock and Wilcox Company

General Electric Company

Wasteco, Inc.

Applied Pollution Control, Ltd.

Erie City Energy Division

8.6 Integral Cyclone Suspension Burner-Combustion Chamber Packaged Unit

8.6.1 Features. Some cyclone burners combine the burner with a combustion chamber. The combustion process is started in a suspension burner and finished in a combustion chamber. The equipment is designed so that the burner operates a vortex-type action in the combustion chamber. Typical of this type of system is the Waycot waste heat incinerator (formerly known as the Waycot 'Turbulator').

This incinerator can burn wood residues of up to 40% moisture content and pieces that pass a 9/64-in. screen. The incinerator is completely automatic. Present units are capable of disposing of 4 units of residue per hour. The manufacturers indicate that smaller and larger units can be designed.

Exhaust gases are predominantly carbon dioxide, water vapour, and nitrogen and will not support combustion; consequently, the system may be safely used to dry lumber. The exhaust gases must be diluted with air, however, to bring them to the proper temperature for drying; consequently, some oxygen will be present. The system is illustrated in Figures 16 and 17 and an operating unit is shown in Figure 18.

8.6.2 Functions of the Components

8.6.2.1 Surge bin. The fuel is pneumatically conveyed from a surge bin which meters the fuel to the 'Turbulator' burner. Fuel must be of proper size and moisture content before it enters the surge bin.

8.6.2.2 Turbulator. The prepared fuel and the primary air source tangentially enter the burner where combustion is initiated. The burning wood then moves to the combustion chamber where secondary air is added and combustion is completed. There is also a secondary combustion chamber through which the exhaust gases pass prior to dilution and utilization. The complete incinerator, comprised of the turbulator burner and two combustion chambers is refractory lined to maintain combustion temperatures of 2600° F.

8.6.2.3 Control system. An automatic control system meters fuel and air to the burner according to exit temperature or process demand. The process requires minimal operator attention.

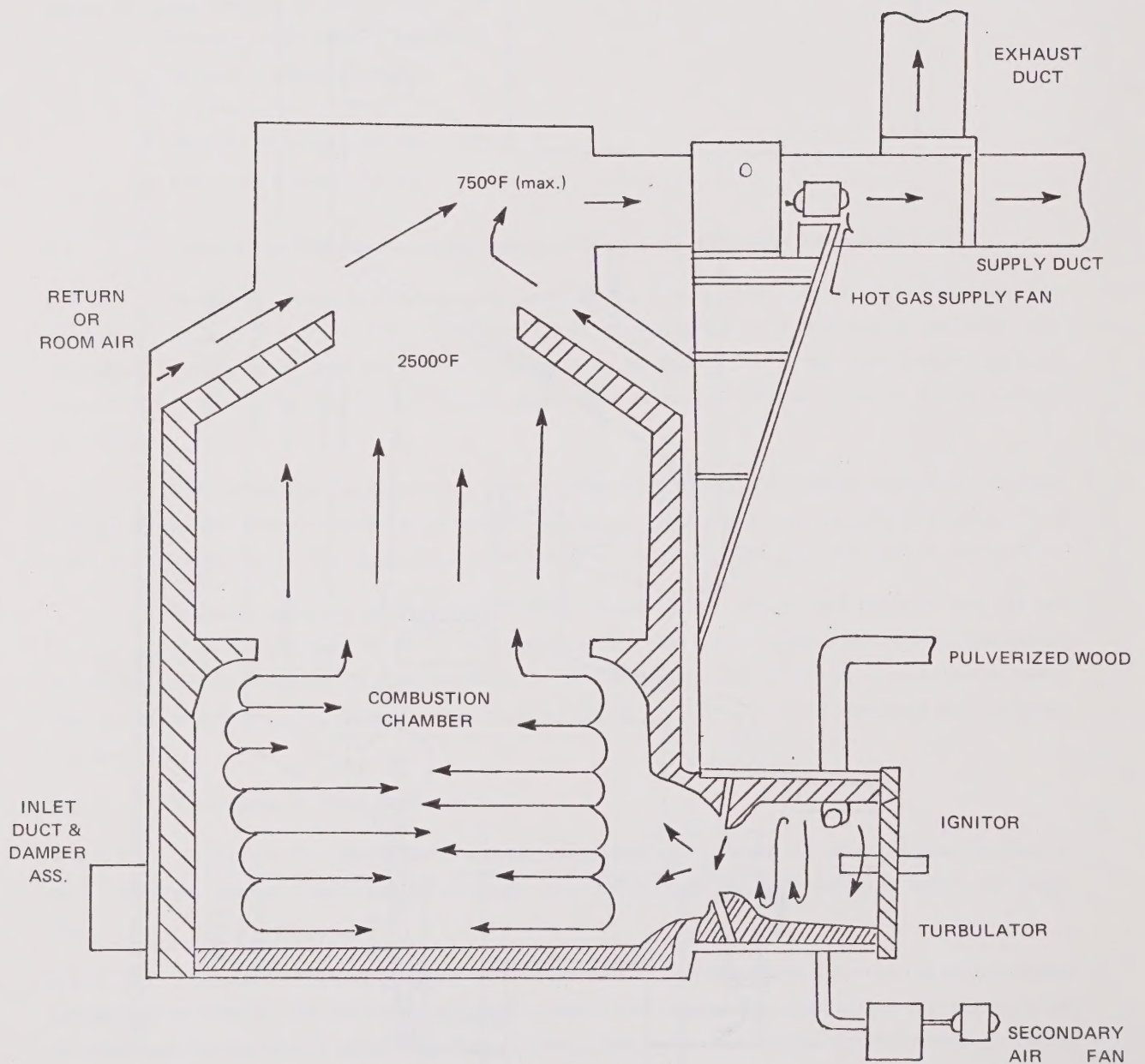


FIGURE 17 'TURBULATOR' CYCLONE SUSPENSION BURNER WITH INTEGRAL COMBUSTION CHAMBER (WAYCOT INDUSTRIES, LIMITED)

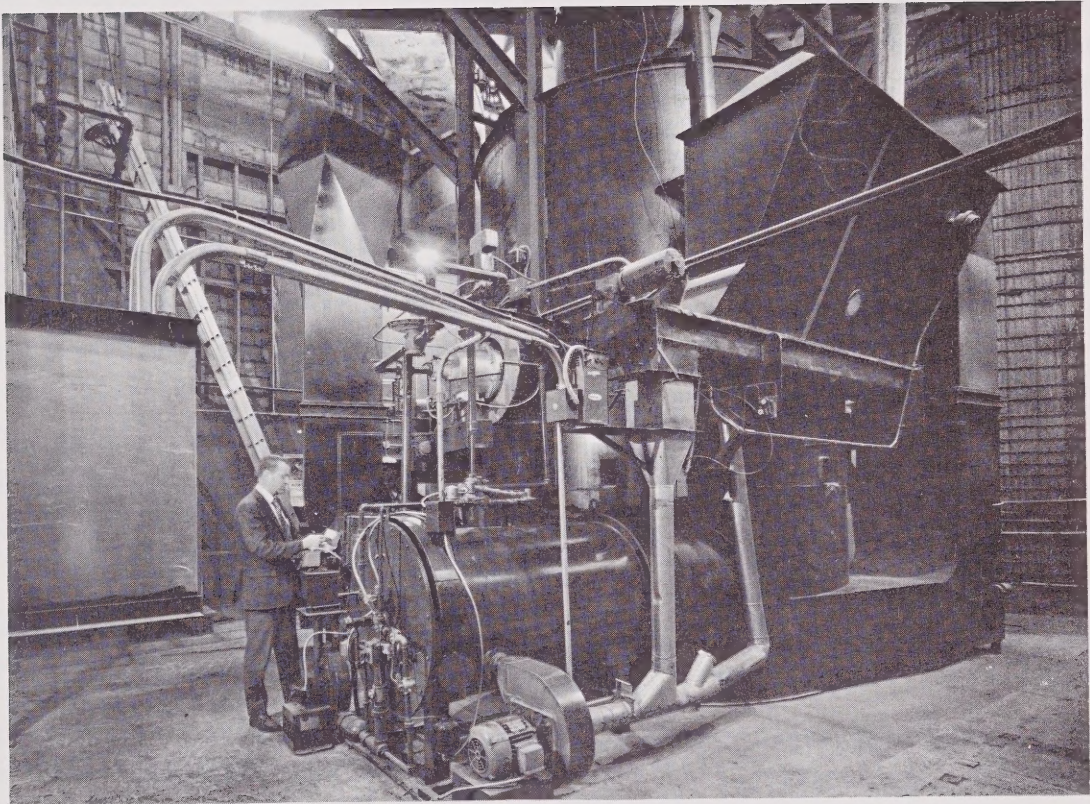


FIGURE 18 CYCLONE SUSPENSION BURNER - COMBUSTION CHAMBER, INTEGRAL PACKAGED UNIT (WAYCOT INDUSTRIES, LIMITED)

8.6.3 Operation. Hugged residues from a sawmill are fed to a storage silo. The silo size depends on the type of operation but the manufacturer recommends sufficient capacity for at least 72 hours operation. From the silo the hugged residues are fed by an unloader to a pulverizer where the fuel is reduced in size to approximately 9/64 in. The upgraded fuel is then blown to a cyclone which deposits the fuel in the metering bin. When the level in the bin reaches an upper limit the unloader is shut off. The silo unloader is activated when the fuel level in the bin drops to a minimum.

Prepared fuel is fed from the bin to the turbulator by an auger. The flow rate is controlled by the temperature in the upper section of the combustion chamber. The auger speed adjusts to maintain a constant temperature in the upper chamber. Fuel is blown from the auger into the turbulator where it is burned. A pilot burner is supplied for ignition. Burning particles are kept in suspension by a secondary air supply. An auxiliary burner can be supplied in the combustion chamber to provide heat during periods of reduced fuel availability. Hot combustion gases inside the refractory chamber are diluted with cool outside air to maintain a temperature of 500 to 700° F in the top plenum.

8.6.4 Air Pollution Potential. Exhaust gases from the Waycot waste heat incinerator are virtually free of particulate material. Emission testing in 1970, using the ASTM procedure, produced particulate emission rates of .004 and .007 gr/scf at 12% CO₂. The fuel during these emission tests was dried sawdust with a moisture content of 8% and an ash content of 0.1%. No other emission tests have been performed on the two existing installations.

8.6.5 Costs. The manufacturer has estimated that the costs for a 4 unit/h system installed, and including a fuel storage silo would be \$250 000 to \$300 000. If fuel storage was not included costs would be \$50 000 lower. While this system includes the cost of a pulverizer it does not include costs for initial hogging of the fuel.

Maintenance costs for the Waycot system are relatively low. The burner must be cleaned only once every six months when burning clean sawdust. The clean-out time is one hour.

8.6.6 Advantages and Disadvantages. The Waycot waste heat incinerator has the advantage of being able to dispose of residue with a relatively high moisture content (40%). Wet bark has been burned successfully. The fuel must still be pulverized so that it may be burned in suspension. Heat from the incinerator can be used in a variety of mill processes, such as kiln drying, space heating and veneer drying.

The 'Turbulator' wood burning system has a 4-year operating record and appears to be reliable. All maintenance is provided by mill personnel.

8.6.7 Comparable Equipment Offering Variations in Design. Integral Cyclone Suspension Burner-Combustion Chamber Units comparable to the Waycot 'Turbulator' system are available from:

Babcock and Wilcox Company

J. R. Mott

8.7 Fluidized Bed Combustors

8.7.1 Features. Fluid bed combustors have been used for a number of years to dispose of materials such as sewage sludge, waste oils and other liquid wastes. Application of fluid bed combustors to the disposal of wood wastes is relatively recent. There are presently three combustors manufactured by Environmental Products, Incorporated, disposing of wood, and another installation is in progress. The Combustion Power Company, Incorporated has run extensive tests using wood as a fuel for their reactor but there are currently no units operating continuously on wood on a commercial scale.

Fluid bed reactors can dispose of wood residues of any moisture content that will support combustion. The residue should be hogged so that it may be transported into the reactor. Exhaust gases must be treated by a cleaning system before being emitted to the air. Reactors are available with capacities of from 0.25 to 8 units/h from Environmental Products and of 0.5 - 8 units/h from the Combustion Power Company. Figure 19 is a schematic diagram of a fluidized bed combustor. A 14 ft diameter unit is shown in Figure 20.

8.7.2 Function of the Components

8.7.2.1 The reactor. The heart of the fluidized bed system is the reactor. The reactor is a refractory-lined steel shell with a bed of small inert particles, usually sand. Air is blown through the sand from the bottom which causes the bed to behave like a fluid. This fluid bed has an extremely high heat transfer rate which aids in combustion. Most of the combustion occurs in the fluid bed with the balance taking place in the vapour space above. Most fluid reactors add air only through the sand bed. The Environmental Products reactor also adds overfire air. Residue is added either through the bed or through a central vertical feed tube depending on the manufacturer.

8.7.2.2 Fluidizing air blowers. Combustion air is usually supplied at a rate of 20% in excess of that required for combustion. Power requirements depend on the depth of the sand bed; the deeper the bed, the more power required to fluidize it.

8.7.2.3 Automatic control system. Most fluidized bed reactors are automatically controlled. The exhaust temperature usually controls the feed rate which in turn controls the amount of combustion air. Automatic units require minimal operator attention.

8.7.2.4 Gas cleaning equipment. All fluidized bed reactors use a gas stream cleaner. Some use a wet scrubber, others dry scrubbers and cyclones, depending on whether or not the heat is being utilized. These collectors are necessary because no ash is retained in the sand bed and because sand is lost to the exhaust gas stream.

8.7.3 Operation. In the Environmental Products 'Fluid Flame' model, wood residues are pneumatically conveyed from a surge bin to the top of the reactor cell. Once the fluid bed has been preheated to 750° F by auxiliary fuel preheaters the wood is admitted to the reactor by means of a high velocity air injection nozzle. Combustion air is supplied through the bed and in an overfire air vortex system, resulting in high combustion efficiencies.

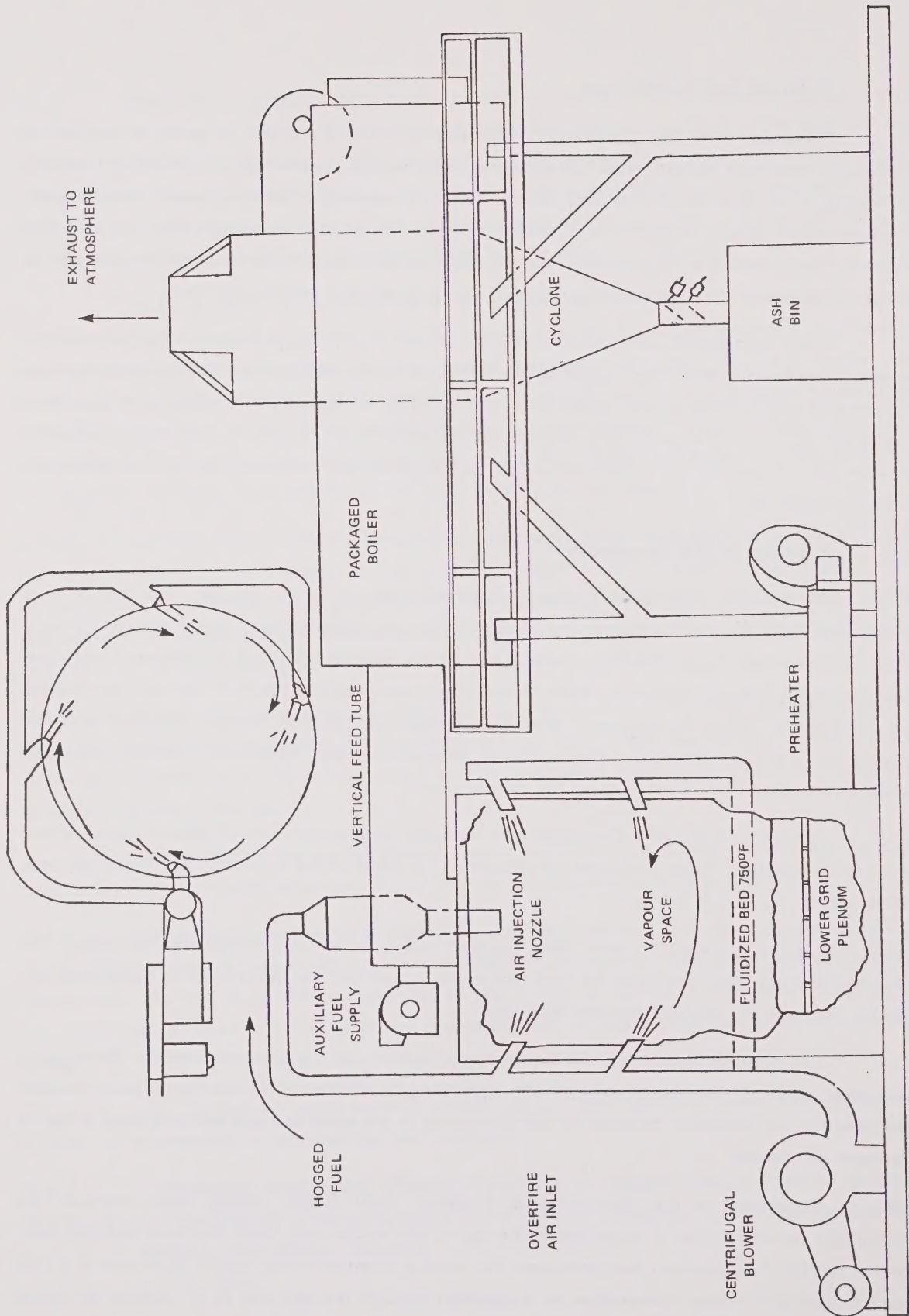


FIGURE 19 FLUIDIZED BED COMBUSTOR SYSTEM (ENVIRONMENTAL PRODUCTS, INCORPORATED)

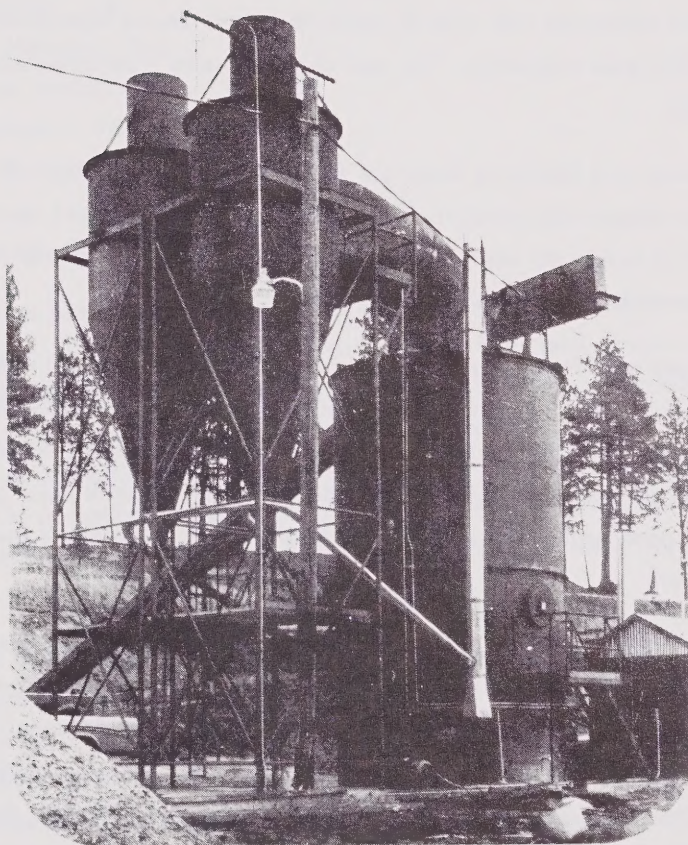


FIGURE 20 'FLUID FLAME' FLUIDIZED BED COMBUSTOR,
(ENVIRONMENTAL PRODUCTS,
INCORPORATED)

The fluid bed temperature will run typically in the 1500° F range while the temperature above the bed may reach 2200° F. The exhaust gases usually exit at 1800° F. The exhaust gas can be used in some process and then cleaned or cleaned and then used, depending on requirements. The exhaust gases may of course be dumped to the atmosphere if not required.

8.7.4 *Air Pollution Potential.* Environmental Products' fluid bed reactor has achieved emission rates as low as .049 gr/scf at 12% CO₂ with an average emission of .074 gr/scf at 12% CO₂. Other fluid bed reactors disposing of sewage sludge or municipal garbage have reported particulate concentrations in the order of 0.02 and 0.03 gr/scf. The emission characteristics are largely dependent on collector efficiency.

8.7.5 *Costs.* The estimated cost of an 8 unit/h fluid bed reactor from Environmental Products is approximately \$150 000 plus installation. The cost of similar units from other manufacturers has been estimated at \$500 000.

Maintenance and operating costs are likely to be relatively high. In addition to costs for power and operation, a considerable amount of sand is required. In a small bed reactor (12 ft diam) 1000 lb of sand was required every 20 days. The refractory must also be repaired occasionally. The gas cleaning system also contributes to high operating costs.

8.7.6 *Advantages and Disadvantages.* Fluidized bed combustors can efficiently dispose of wet hogged wood residue. For direct use, inorganic particulate matter must be removed in a gas cleaning device. Costs are relatively high per unit of capacity. Combustors provide a simple means of obtaining complete combustion of complex or variable solid residues. Clean, hot combustion gases can be produced under pressure, and consequently this system is more suitable for utilization of heat from wood residues than for straight disposal.

Very little is known about the reliability and safety of the 'Fluid Flame' combustor when operating on wood residues. Fluidized bed combustors are operating reliably on sewage sludge on a commercial scale. A great deal of work is in progress on commercial-scale units to recover heat energy from solid municipal refuse and some of this technology will be applicable to wood residues. Commercial-scale demonstration units are in operation and are designed by Combustion Power Company, Incorporated to produce electricity from gas turbines using hot gases under pressure.

8.7.7 *Comparable Equipment Offering Variations in Design.* In addition to Environmental Products Incorporated other companies with considerable experience offer fluidized bed combustors and reactors. They have experience with materials such as solid municipal refuse, pulp mill black liquor, sewage sludge, etc.

Combustion Power Co., Inc. - CPU-400 Combustor

- uses sand bed fluidized with combustion air
- ash and a small amount of fine sand leaves the fluidized bed with the combustion gases. Particulate matter is removed in a dry granular-bed gas cleaner

- when operated under pressure, cleaned combustion gases run gas turbines to generate electricity. Two different-sized turbo-generators are available, 1000 kW and 3000 kW
- commercial-sized fluidized combustors, 9 ft 6 in. diam, have run for 101 h burning 1 000 000 lb of wood residue or 5 units/h
- no commercial-sized units using wood are in operation at the moment
- systems are designed more for heat utilization and electric power generation
- fluidizing velocities as high as 20 fps are used providing high capacity and therefore a relatively small-sized combustor.

Black-Clawson, Inc.

Dorr-Oliver, Inc.

Foster Wheeler Corp.

Copland Systems, Inc.

Wheelabrator-Frye Lurgi

AWT Systems, Inc.

8.8 Gasification Systems

8.8.1 Features. Gasification of wood residues involves the thermal decomposition of wood with a deficiency of oxygen in the presence of water to produce hydrogen, carbon monoxide and methane, carried in nitrogen and carbon dioxide. The gas produced can be burned to produce hot, clean combustion products. Ash and incombustibles are removed from the reactor while it is in operation and disposed of in a landfill. Gases produced can have a heat value between 170 Btu/ft³ and 350 Btu/ft³. There are several pilot plants in operation for the gasification of solid organic wastes but no commercial plants are known which specifically use wood residues. The process has merit for larger wood processing facilities.

Moore Canada Limited, Vancouver, British Columbia, is operating a pilot plant built to 1/10 scale and is processing about 0.75 units/h of hog fuel generating about 6 million Btu/h of useful heat from combustion of gas with an additional 3.5 million Btu/h flared to the atmosphere. The turn down ratio of the gasification reactor is 2:1. The burner for the low Btu gas is insensitive to the air/fuel ratio. It offers a 3:1 turn down for stoichiometric combustion of gas and a 10:1 turn down on excess air. Design for a commercial-sized system to handle 5 units/h, based on results of 15 months test operation of the small scale plant, is to be completed by the spring of 1975. Figure 21 is a schematic diagram of the operating wood gasification plant and the 1/10 scale test plant is shown in Figure 22.

8.8.2 Function of the Components

8.8.2.1 Reactor. The reactor is a refractory-lined vertical steel cylinder. Fuel pieces up to 8 in. are added through the top of the reactor by a star valve feeder. Air and water are injected at the bottom of the reactor. Ash, incombustible minerals and tramp metal are removed from the bottom as granular ash or clinker. Air is preheated before entering the reactor. Gasification is controlled by the air/steam blast rate into the bottom of the reactor. Gas production can be rapidly adjusted to meet demand. Wood feed

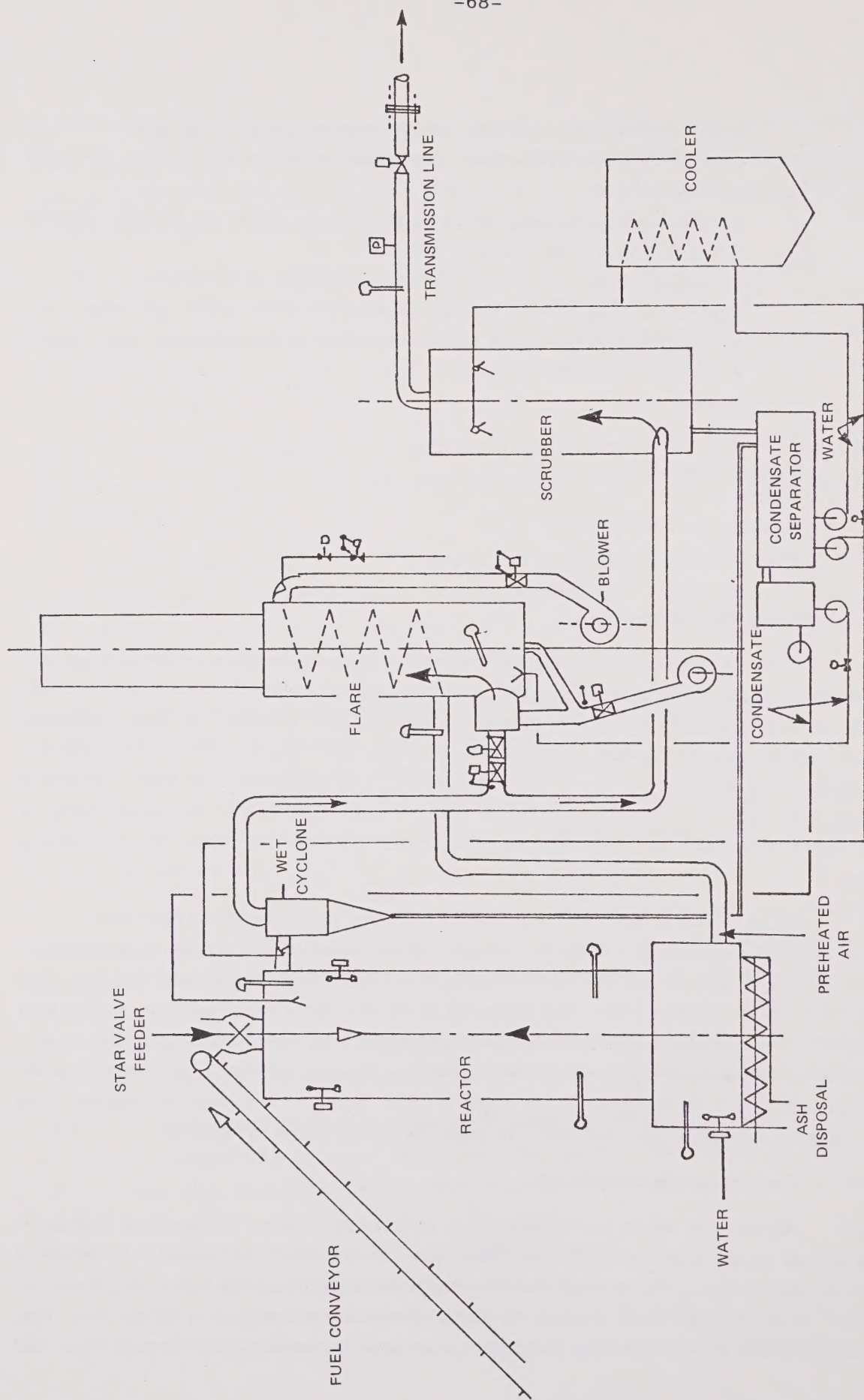


FIGURE 21 WOOD GASIFICATION SYSTEM (MOORE CANADA, LIMITED)

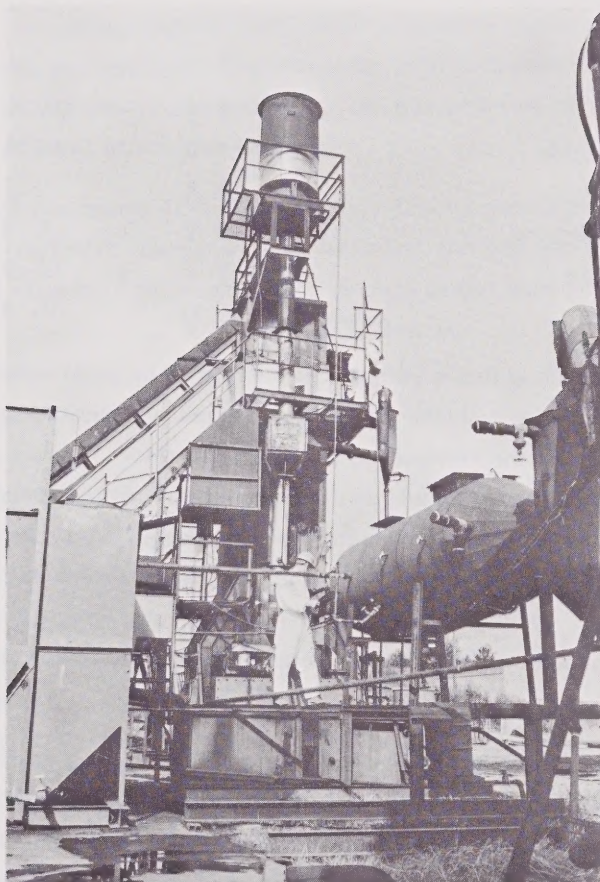


FIGURE 22 1/10 SCALE GASIFICATION PILOT
PLANT CONVERTING WOOD TO
COMBUSTIBLE GAS (MOORE
CANADA, LIMITED)

rate is controlled by the level of solids at the top of the reactor, and ash removal is controlled by temperature sensors.

8.8.2.2 Gas cleaning equipment. Products of gasification pass through a wet cyclone after leaving the top of the reaction chamber. This cyclone removes water and condensible organic compounds from the gas. The product gas is cooled from 200° F to about 100° F by passage through the wet cyclone and then through a secondary gas cooler. The gas output from the process has a chemical composition with the following range of concentrations:

	Dry gas (% Vol.)	
Hydrogen	17.4	19.8
Carbon monoxide	21.8	26.0
Methane	2.5	2.7
Other hydrocarbons	0.5	0.9
Carbon dioxide	9.2	11.9
Nitrogen	42.0	45.4

8.8.3 Operation. Wet hog fuel is admitted to the reactor by a star valve feeder. Hot air and water are fed to the reactor through the fuel pile. Not enough oxygen is present to support full combustion, and only the gasification portion of the combustion process takes place. Product gases leave the reactor at about 200° F and are passed through a wet scrubber to remove any condensate. The gas stream is split so that one-third of the gas is used to incinerate the condensate (tar and water). The remaining gas is cooled and passed through a dry scrubber. It may then be stored or burnt in a special burner. Heat from the burner can be used in many plant processes, including dry kilns, log vaults, veneer dryers and package boilers. Most manufacturers are considering a minimum plant size of 100 tons/day (dry wood).

8.8.4 Air Pollution Potential. The air pollution potential for the gasification process is low. The only combustion is of a gas with very few or no incombustible components. Tests performed on a pilot plant measured 0.010 gr/scf for the incinerator flare and 0.004 gr/scf for the process burner.

8.8.5 Costs. The capital cost for a plant processing 5 to 7 units/h is estimated at \$400 000. This cost includes a feed conveyor, reactor, wet scrubbers, a gas burner and hot gas furnace. The pipeline conveying gas from the reactor to the furnace is not included. A unit this size is being designed to handle the wood residue from a sawmill cutting 100 000 fbm/day. Operating costs are estimated at about \$70 000/year. Assuming operation 16 h/day, 5 day/week 200 days/year at 5 units/h, operating cost (not including amortization) would be about \$4.40/unit.

8.8.6 Advantages and Disadvantages. The gasification process has large-scale disposal capability for high-moisture-content hog fuel (40-60%) with very low particulate emissions to the atmosphere. The process is not designed for dry wood (below 30% moisture). The gas produced can be burned in a number of processes requiring heat; however, it contains carbon monoxide which is colorless, odorless and poisonous. Leaks in the product gas lines could be dangerous.

Commercial plants are being engineered to handle wood residues from sawmills with capacities between 50 000 and 150 000 fbm/day. The present pilot plant built to 1/10 scale is processing about 0.75 units of wet hog fuel per hour to provide design data. The commercial wood gasifier will have the important advantage of being available for on-site installation at individual mills and producing combustible gas for 'in-house' use. The gasification process also provides an opportunity for a consortium of mills to deliver wood residue within an economic trucking radius to a central plant. The low-Btu combustible gas may be piped limited distances to nearby mills for direct use in heating dry kilns and mill space. It can also be used in internal combustion engines of motor-generator units to produce electricity to power sawmills, dry kilns, etc. Depending on local circumstances and arrangements with public utilities supplying natural gas and/or electricity, the gas-powered motor-generator unit may be at the central gasification plant or at the individual mill.

Assume a mill producing 100 000 fbm/day (24 h) generates 70 units (50% moisture content) per day of wood residue. If sawing on a 2-shift basis, the gas generation plant would have to handle a minimum of 4.4 units/h. The distribution of energy would then be as follows:

<i>Generation</i>	10^6 Btu/day	10^6 Btu/h
Gross energy in wood	1 287	
Heat in gas from plant	957.7	
<i>Less</i>		
Heat for condensate incineration	440.6	
Net heat available for use	517.1	21.54
Fraction of heat available for use	54% of gas generated	
<i>Utilize in Dry Kilns</i>		
Gas to heat kilns	230.6	9.61
Gas to mill heating	13.8	0.57
Excess gas to flare, etc.	272.7	11.36

Instead of being dumped to the atmosphere, excess heat can be used in a waste heat boiler to produce about 8600 lb of steam/h, or in a motor-generator set to produce about 22 700 kWh/day of electricity for mill operation. By utilizing heat available from the gasification of its wood residue for dry kilns and electric power, a sawmill can approach energy self-sufficiency.

The gasification reactor operates slightly below atmospheric pressure. Pressure relief valves prevent over pressurization. The deep bed of wood minimizes blow-through, and control of air/steam blast rate minimizes formation of combustible gas mixtures in the reactor. Shutdown is claimed to be almost immediate since gas generation stops on shutdown of the air blast.

Since a commercial-scale plant, designed to run on wood residue, is not in operation no comment can be made on reliability. Design is based, however, on 15 month's experience with a 1/10 scale operating plant that has run continuously using typical hog fuel from the interior of British Columbia. Experiments have also been performed using wood from other locations. The fraction of heat in the form of usable gas as a percentage of gross heat in wood residue feed to the system is shown for hog fuels at two moisture contents:

Moisture content of hog fuel (wet basis)	Fraction of Heat as Gas	
	50%	40%
In gas from gas plant	74.4%	74.4%
In gas available for use	40.2%	49.4%

8.8.7 Comparable Equipment Offering Variations in Design. While only a few organizations having specific performance data on wood are known, there are many organizations operating pilot plants or building demonstration plants for gasification of coal and organic solid waste. Since municipal refuse is about 50% wood-based waste (paper, etc.) plus about 25% wet vegetable waste, much data from these gasification studies will be applicable to wood. Organizations active in gasification of municipal solid wastes are:

Garrett Research, Division of Occidental Petroleum
Monsanto Landgard Process, Monsanto Enviro-Chem Systems
Hercules, Inc.
Union Carbide
Lurgi
Foster-Wheeler Corp.
Weyerhaeuser
University of West Virginia
Torrax
Battelle

The Union Carbide gasification process uses oxygen instead of air to produce a high-Btu-value gas. The University of West Virginia process uses heat from the combustion of charcoal to provide energy for pyrolysis. Combustion and pyrolysis take place in separate reactors to prevent nitrogen dilution of the combustible gas product.

8.9 Fluid Bed Charcoal Reactor

8.9.1 Features. Work to produce gas from sawmill residue using a fluidized bed began in 1947 at B.C. Research. The process was modified in 1959 to make charcoal the main product. It was designed for sawdust, thereby allowing use of the entire range of sawmill residues which could be hogged to sawdust particle size. Alberta Industrial Developments Limited has recently started operating a 12 ft by 7 ft commercial-sized fluidized bed reactor based on this process. Wet fuel is fed continuously into the bottom of a fluidized charcoal bed. Hot combustion gases and air convert the wood to charcoal and combustible gas with a heat value of 125 to 250 Btu/scf. The amount of gas increases as the fluidized temperature rises and charcoal yield decreases. Hot fluidizing gas for start-up is produced by a natural gas furnace, and combustible gas from the wood is burnt in a second furnace. A blower supplies hot gas and air to the fluidized bed. Surplus hot gas may be utilized for process heat or dumped to the atmosphere. Incombustible inorganic matter passes continuously out of the reactor bed with the charcoal product. The process is therefore a continuous production unit, a source of clean heat, or a disposal unit, depending on operation. The unit now operating is able to handle 2.5 units/h or about 2.5 tons dry

wood/h at 40% moisture content (wet basis). Charcoal production is rated at 0.5 tons/h. Figure 23 is a schematic diagram of the fluidized bed charcoal process and the operating plant is shown in Figure 24.

8.9.2 *Function of Components*

8.9.2.1 *Reactor.* The reactor is an insulated stainless steel shell. Sawdust-sized charcoal is the only fluidizing medium. Hogged wood residue is metered into the bottom of the fluidized bed above the gas distribution plate by a feed screw and is rapidly and uniformly dispersed throughout the fluid bed which is usually 6 ft deep. Charcoal product overflows from the top of the bed through two down pipes. Some combustion takes place in the bed to maintain operating temperature. The top of the reactor is designed as a large rupture disc to relieve pressure in the event of an explosion.

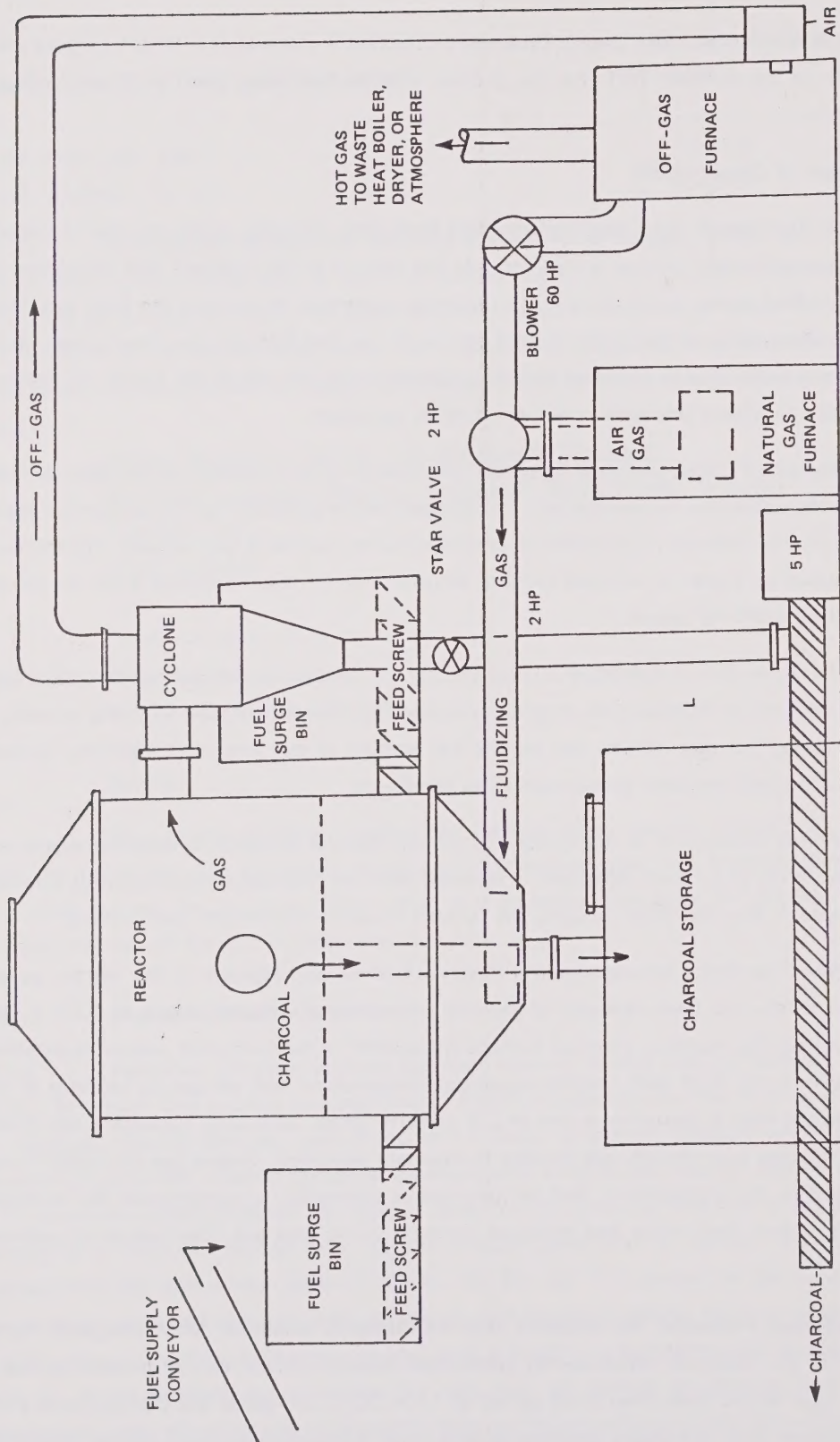
8.9.2.2 *Fluidizing gas.* Provision is made to supply combustion air to fluidizing gas furnaces at twice the volume theoretically necessary for combustion. Bed temperature is controlled by the amount of excess air. Combustion gas plus air volume is controlled to maintain correct fluidizing gas velocity. For start-up, fluidizing gas is supplied by a gas- or oil-fired furnace. Normally, combustion products from the off-gas furnace are supplied by a 60 hp blower.

8.9.2.3 *Control system.* Bed temperature is controlled by the temperature of combustion gases from the off-gas furnace. Volume of fluidizing air must be measured to maintain proper fluidizing velocity in the bed. Dampers on the hot gas transfer fan control the amount of gas extracted from the furnace. Pressure drop across the bed indicates proper operating conditions.

8.9.2.4 *Gas cleaning equipment.* A dry cyclone in the off-gas line removes charcoal carryover and returns it to the main body of product. Most ash is retained with the charcoal and is removed from the system with the charcoal. Any carryover passing the cyclone is burned in the off-gas furnace.

8.9.3 *Operation.* Two surge bins equipped with screw feeders, and adjacent to the reactor, supply it with wood residue which has been reduced to sawdust. A measured volume of gas at 120° F, and containing excess air from the auxiliary start-up furnace is supplied to the partly full reactor to establish fluidizing velocity. When the fluid bed reaches operating temperature and off-gas is burning in the off-gas furnace, sawdust feed is started at a rate of 2.5 units/h. When operating conditions are stable, gas at 1200° F is extracted from the off-gas furnace to maintain operation. Excess gas at 1200° F may be utilized or dumped to the atmosphere. Bed temperature is controlled to compensate for moderate changes in fuel composition (heat value and moisture content). Large changes may require adjustment of feed rate.

8.9.4 *Air Pollution Potential.* No emission data are currently available. Most inorganic matter leaves the reactor with the charcoal; consequently particulate emission should be comparable to that of a slagging cyclone-type burner (less than 0.08 gr/scf at 12% CO₂). Off-gases are cleaned with a dry cyclone, not a wet cyclone as in the Moore gasification pilot plant. Particulate emission should, therefore, be greater than 0.1 gr/scf at 12% CO₂.



Cyclone has outlet star valve to remove charcoal.
Natural gas fired furnace fluidizes gas for start up.

FIGURE 23 FLUIDIZED BED WOOD CHARCOAL REACTOR SYSTEM



FIGURE 24 'THERMEX' FLUIDIZED BED REACTOR (ALBERTA INDUSTRIAL DEVELOPMENT, LIMITED)

8.9.5 Costs. The preliminary cost estimate for a wood charcoal-gasification system handling 2.5 tons/h (dry basis) of hog fuel is \$125 000 (September 1974). Cost of total equipment consisting of the reactor, fans, cyclones, receivers, instruments and controls is estimated at \$78 000 and cost of foundations, installation and engineering is estimated at \$47 000. Sawdust storage, charcoal handling and supply of power and land are not included. The cost of installing multiple units would be less. Operating costs are estimated at \$5.00 to \$7.00/ton of charcoal or about \$1.00 to \$1.40/unit of hog fuel.

8.9.6 Advantages and Disadvantages. The fluidized charcoal-gasification system can utilize wood residue of mixed composition with high ash and moisture content. The only upgrading required is sizing to sawdust. Reactor operating temperature is low enough to prevent slagging. The process is continuous, able to be automated and requires only moderate attention. The system produces a marketable product as well as clean hot gas for process use or disposal. The relative amount of charcoal and gas can be modified by altering reactor temperature. Systems are sized for on-site installation at individual mills. Wood residue volume is reduced by one fifth, and most of the heat value in the wood is stored in a more compact form. The process is new, however, and must still demonstrate that it can run on a reliable and sustained basis, producing a marketable product.

The system operates with combustible gases at an elevated temperature in the presence of excess air, and an 'explosion potential' does exist as with all gasification reactions. A large rupture disc is provided in the top of the reactor to relieve excess pressure.

8.10 Applications Summary

To assist the user of this report in relating alternative thermal wood decomposition systems to specific situations, a summary is provided in Table 21 in the form of a matrix relating three wood residue characteristics and 8 types of thermal decomposition systems. The object is to indicate the ability of each system to handle various types of wood residue. The emphasis is on disposal but with opportunities for utilization of heat or production of products generally increasing from left to right. A cost summary of the various systems is provided in Table 22.

9 RESEARCH AND DEVELOPMENT

9.1 General

When reviewing the state-of-the-art of wood residue, utilization and disposal, several areas emerge where research and development would be beneficial.

9.2 Conical Incinerator

There is merit in the disposal of mixed wood residues by controlled pile burning in conical incinerators designed to apply principles of good combustion. In the past this type of incinerator has been abused. Recent modifications to automatically control air supply, operating temperature and fuel feed rate

TABLE 21 APPLICATIONS SUMMARY*

State of Development	Modified conical incinerator	Pit incinerator	Multiple chamber incinerator	Cyclone incinerator	Fluid bed combustor	Gasification	Cyclone burner/chamber	Fluid bed charcoal reactor
Range of Particulate Emission, gr/scf	Now 0.7-15	Now 1-25	Now 0.3-10	0-1 yr 0.5-10	0-4 yrs 0.2-10	0-1 yr 0-10	0-1 yr 0-10	2-4 yrs 0.01-10
Moisture Content (wet)								
0 - 10%	x	x	x	x	x		x	
10 - 40%	x	x	x		x		x	x
40 - 60%	x	x	x		x	x		
60%	x	x	x		x	x		
Capacity (units/day)								
0 - 25	x	x	x	x	x		x	
25 - 100	x	x	x	x	x		x	x
100 - 200	x	x			x	x	(a)	
200	x	x				x		
Residue Type (size)								
Sanderdust			x	x	x		x	
Sawdust	x		x	x	x	x	x	x
Shavings	x		x	(b)	x	x	(b)	
Chips	x	x	x		x	x		
Bark	x	x	x		x	x		
Slabs	x	x						
Trim Blocks	x	x						
Hog Fuel	x		x		x	x		x

* Increasing potential for utilization from left to right

(a) Available on special order.

(b) Other residue must be prepared by sizing with a hammermill.

TABLE 22 COST SUMMARY, DOLLARS, SEPTEMBER 1974*

Capacity (units/h)	Modified conical incinerator	Pit incinerator	Multiple chamber incinerator	Cyclone suspension burner	Cyclone burner/ chamber/ packaged unit	Fluidized bed combustor	Gasification reactor	Fluid bed charcoal reactor
0 - 1				(slagging) 68 000				
1 - 2	33 000			70 000				
2 - 3			165 000	75 000				125 000
3 - 4		25 500	233 000	100 000				
4 - 5		27 500		110 000	250 000		400 000 (complete)	
5 - 6	60 000							
6 - 7		28 000						
7 - 8	68 000	30 000				150 000		
8 - 9						500 000		
9 - 10		31 500 42 800						
10 - 11	82 000							
11 - 12								
12 - 13								
13 - 14								
14 - 15	104 000							

*Burners and controls only. Freight, foundations, conveyors and taxes, if applicable, could double costs.

have produced systems which can comply with particulate emission criteria in many areas. Temporary malfunctions still occur, however, as do undesirable visible emissions. Pretreatment of wood residue prior to incineration would provide more uniform supply to the burner resulting in consistent operation. The following improvements are suggested:

- (a) Utilization of some hot combustion gas in a 'hot hog' to remove some moisture while reducing wet wood residue to a uniform particle size;
- (b) Development of an inexpensive pile storage for wet or partly dried hog fuel that would allow some mixing if needed but would require no attention when feeding to the incinerator even in sub-zero weather.

9.3 Pit Incinerator

The air-curtain pit incinerator can be portable and is relatively inexpensive. These two facts should make it attractive to the large number of sawmills (over 80%) producing less than 40 000 fbm/day. The following improvements are suggested:

- (a) Development of inexpensive earth-refractory mixtures or movable refractory pit walls that will enable the incinerator to operate with wall temperatures in the order of 2000° F to allow good combustion and high rates of radiation;
- (b) Development of a method to mechanically feed the pit incinerator thereby minimizing operator attention and allowing regulation of feed rate;
- (c) Development of a feeding method for wood residues containing sawdust so that the sawdust can penetrate through or be inserted into the vortex combustion zone. Once inside the vortex, small particles will tend to stay until burnt, thereby minimizing particulate emission and discharge of sparks;
- (d) Provision of a short exhaust stack on one side of the pit. Combustion gases can then travel horizontally along the eye of the vortex. This design provides a long residence time for combustion of larger particles and also provides some opportunity for cleaning exhaust gases in a low-pressure-drop scrubber;
- (e) Development of reliable emission measurement methods.

9.4 Inventive On-Site Application for Clean Hot Gases

While the multiple chamber 'pile burner'-type incinerator is both a disposal unit and a clean hot gas generator, cyclone burners and fluidized bed combustors are predominantly clean hot gas producers. Capital costs of wood-fired boilers are two to four times the cost of equivalent gas- or oil-fired units and because of this many operators find it financially more attractive to use natural gas as primary fuel and to waste the heat from wood residue to the atmosphere. Cyclone burners producing clean hot gases are comparable in installed cost to conical incinerators. However, some require dry, sized fuel to operate, and drying equipment increases capital costs. If burners could use wet (40% moisture), sized wood residue, and use hot gases directly as needed, capital costs would be comparable to gas- and oil-fired equipment.

The production of clean, hot gases for direct use or disposal to the atmosphere, requires the development of methods for controlling salt emissions from hog fuel-fired power boilers when burning hog fuel from logs floated in salt water.

9.5 Regional Energy Recovery Plants

In many mills the heat energy available from wood residue greatly exceeds demand. For example, a sawmill cutting 100 000 fbm/shift generates wood residue capable of producing 153 million Btu/h. The mill's dry kilns only require 10 million Btu/h. Several processes are available to convert wood and other solid organic waste into basic energy forms such as electricity, fuel gas or fuel oil. Incineration with steam or electric generation represents the best proven technology but pyrolysis-to-fuel gas systems are rapidly being developed.

A central energy recovery plant using wood residues can be designed to meet environmental standards. Increasing emphasis on maintenance of environmental quality has resulted in a serious wood residue disposal problem for many wood processing facilities. Technology is available to convert wood and other solid organic waste into basic energy forms. Advanced technology, such as the CPU-400 combined system, using pressurized hot gases from a fluidized bed combustor directly in gas turbine generators, indicates increased efficiencies in converting heat to electric energy at a capital cost per kilowatt hour that can be about half that of a typical utility. Consequently, a central regional energy recovery plant can provide a solution to the wood residue disposal problem and provide a valuable source of clean energy at a time when energy costs are increasing rapidly. While demonstration facilities have been operated there are no known commercial units using wood.

The problem revolves around the ability to utilize the energy generated. Steam can be transported only a limited distance. Electric power is transportable but the large blocks of power that would be available would need to be sold to an existing electric utility power grid. An associated problem is the ability to sell electricity to the utility at a price that would allow the regional energy recovery plant to operate economically. In British Columbia the British Columbia Hydro and Power Authority has made a study for their own use on the generation of electric power from hogged fuel. Since wood is a *renewable* non-fossil fuel that can provide relatively clean heat at a fuel cost of thirty to seventy-five cents per million Btu, the use of wood burning regional power generating facilities warrants serious study.

9.6 Fuel Gas from Gasification of Wood

Gasification of solid organic wastes has been known for many years but there was little incentive to develop commercial-scale systems because of the availability of inexpensive energy in oil and natural gas.

There are five major processes for the gasification of coal. The Lurgi process has been commercialized in Europe and a \$250 million facility is planned for New Mexico in 1976. There is active development of other processes and demonstration plants.

There are at least six processes for the production of gas (not liquid products as in pyrolysis) from solid municipal wastes (6). The oxygen system developed by Union Carbide is reported to be in commercial operation at South Charleston, West Virginia, processing 200 tons/day of solid refuse and producing 7 million Btu/ton from gas at about 300 Btu/scf. This is a very active field and developers have done pilot plant work and are planning demonstration plants.

The only known gasification units specifically for wood are one now in commercial design by Moore Canada Limited and a commercial-scale fluid bed reactor by Alberta Industrial Developments Limited producing charcoal plus combustible gas. The gas produced is very low in sulphur.

Both processes involve partial oxidation with hot steam to produce carbon monoxide and hydrogen plus carbon dioxide. Low-heat-value gas (150 to 300 Btu/scf) is suitable for 'on-site' use or use within several miles but is not interchangeable with natural gas and cannot be transported economically. Some processes pass this gas through a catalytic shift converter to increase the hydrogen to carbon monoxide ratio at 3:1, ($\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$). After removing carbon dioxide, water, etc. the shift gas is passed through a catalytic methanator to produce methane ($3\text{H}_2 + \text{CO} \rightleftharpoons \text{CH}_4 + \text{H}_2\text{O}$). This gas is of pipeline quality and may be used as a supplement to or alternative for natural gas. The literature indicates that prices of about \$1.00/million Btu for synthetic gas are feasible (8).

Processes and process economics for producing and refining combustible gas from surplus wood residues deserve serious study, particularly in relation to regional energy recovery plants. The higher heating value of the refined gas will permit transportation over a wider area.

9.7 Production of Fuel-Grade Methanol

Although methanol has a heat value of 9600 Btu/lb compared to 21 600 Btu/lb for gasoline, it provides more power in engine cylinders. A modified automobile engine has been run successfully on 100% methanol producing emissions well below the United States Federal Standards for 1975-76. Blends with gasoline showed a maximum in fuel economy (miles per gallon) at about 20% by volume. These blends have the significant advantage of not requiring major changes in storage and distribution facilities for liquid fuels.

Crude methanol from a medium pressure synthesis process has been successfully used to generate electricity. A fuel-grade methanol plant is planned for Saudi Arabia with deliveries to the United States expected in 1976. Another plant is planned for Iran. Methanol is more economical to ship than liquid methane natural gas. Some comparative data on methanol and other fuels are itemized in Tables 23 and 24 (7).

Gas from the steam/oxygen gasification of wood after removal of tars, etc., consists mainly of carbon monoxide (CO), carbon dioxide (CO₂), and hydrogen (H₂) together with some methane (CH₄) and other hydrocarbons. Conversion to methanol would utilize the following steps:

- catalytic shift to increase H₂:CO to 2:1
- use Imperial Chemical Industries low pressure (800 to 1600 psi)
- copper-based catalytic conversion process following the reaction:

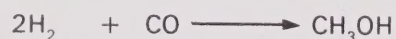


TABLE 23 COMBUSTION ENERGY DENSITY OF FUELS

Fuel	Btu/lb	Btu/gal (U.S.)
Hydrogen gas	59 000	3.7
Methane gas	29 000	16.0
Hydrogen, liquid	59 000	3 200
Methanol	9 600	59 000
Gasoline	21 000	110 000
Coal	15 000	160 000
Wood (solid)	8 400	53 000

TABLE 24 RELATIVE COSTS OF FUEL

Fuel	\$ Per million Btu (1973)	
	Production	Storage
Gasoline	1.00 - 3.00	0.10 - 0.75
Methanol	1.20 - 1.60	0.15 - 1.00
Methane	0.15 - 0.40	-

The minimum plant size for methanol conversion is currently 150 tons/day. The heat value of fuel grade methanol at this capacity would be 2880 million Btu per 24-hour day. The heat value of wood waste from a 100 000 fbm sawmill running 3 shifts/day is about 3670 million Btu per 24-hour day (bark plus sawdust and shavings).

Converting the gas from wood to methanol offers the following opportunities:

- energy is stored in a more compact form (compared to gravity-packed hog fuel);
- fuel-grade methanol has been used as fuel alone, as a blend with gasoline and promises to become more widely used;
- methanol can be stored conveniently;
- fuel-grade methanol can be shipped to markets some distance away from the source of wood residue surplus.

Technologies for gasification, shift conversion and methanol conversion are known and processes are operating or are in active development. At present, however, the smallest methanol plant costs about \$5 million. Fuel-grade methanol made from renewable, non-fossil, solid organic carbon such as wood, could provide a perpetual supply of energy in liquid form which could be stored, distributed and used in existing systems. Initially it may be used to preserve and allow distribution of the energy in wood residue that is now wasted. It would be considered a supplement to existing petroleum-based fuels. There is already support in the literature indicating the feasibility of growing wood and other crops (such as corn) specifically for energy. Conversion to fuel-grade methanol could then provide a perpetual supply of clean energy in a conventional form.

A wood processing facility producing 300 000 fbm/day generates enough wood residue to produce 150 tons of methanol per day. Some of this methanol could be used on site. The excess is in a marketable form. The technical and economic feasibility of an integrated modular gasification-methanol conversion plant for 'on-site' installation deserves further study.

10 CONCLUSIONS

10.1 General

Seventeen percent of the wood residue in British Columbia is produced by mills cutting less than 40 000 fbm/shift (89% of total number of mills) while 68% of the residue is generated by mills cutting between 40 000 and 200 000 fbm/shift (10% of total). Thus, the majority of wood residue is produced by mills generating between 37 to 183 tons of dry wood per day.

There is currently a surplus of wood residue from wood processing facilities in the Interior of British Columbia. The present gross heating value of this surplus is 51 000 00 Btu/year. With heat from natural gas costing fifty-five cents per million Btu (and increasing), the value of the heat in wood residues represents a value of over \$28 000 000/year.

Wood is a renewable non-fossil source of energy which preliminary studies indicate might be harvested or cultivated specifically as an energy source that could be economically competitive with conventional non-renewable fossil fuels. However, present wood-fired power boilers cost 2 to 4 times as much as equivalent gas- or oil-fired facilities. The capital cost burden makes wood-burning facilities financially less attractive than gas- or oil-fired units even in cases where adequate heat is available from surplus wood residue. In addition, wood can only be transported economically for 100 - 200 miles.

Increasing emphasis on maintaining environmental quality has resulted in serious wood residue disposal problems for many wood processing facilities. At many mill sites the heat available from non-marketable wood residues greatly exceeds demand. There is a need to develop inventive new uses for this heat or to transport it where it can be utilized.

10.2 Technology

Seven different systems have been identified and discussed for the on-site disposal of wood residues by thermal decomposition processes:

- Modified Conical Incinerator – primarily for disposal
- Pit Incinerator (portable and fixed) – primarily for disposal
- Multiple Chamber Incinerator – disposal and utilization
- Cyclone Suspension Burners – utilization, some disposal
- Fluidized Bed Combustors – utilization
- Gasifiers – utilization and disposal
- Fluidized Bed Charcoal Reactors – utilization.

The modified conical incinerator and pit incinerator are appropriate for the large number of mills cutting less than 40 000 fbm/shift. The remaining five systems are more suitable for mills cutting over 40 000 fbm/day and having a demand for the clean, hot gases that these facilities produce. Fluidized bed combustors and gasification units provide systems producing gases that may be used directly in gas turbines to produce electricity and process steam. The charcoal reactor produces a marketable product plus clean, combustible gas for on-site use.

10.2.1 Air Pollution Potential. The air pollution potential of the seven different wood residue disposal systems reviewed may be rated as follows:

Modified Conical Incinerator. Particulate emissions and plume opacity are significantly lower than conventional teepee burners. Under proper operating conditions particulate emissions can be less than 0.10 gr/scf and plume opacity can be less than 20% (Ringelmann 1).

Pit Incinerator. The concentration of particulate matter in exhaust gases is dependent on material burnt and incinerator operation. Particulate emission may exceed 0.10 gr/scf but particles usually fall within a radius of 200 ft.

Multiple Chamber Incinerator. The few incinerators of this type installed for disposal of wood residue have produced particulate emissions of less than 0.1 gr/scf without combustion gas cleaners.

Cyclone Suspension Burners. This type of burner can produce exhaust gases very low in particulate matter. Good emission data are scarce but tests have reported particulate emissions ranging from 0.004 to 0.084 gr/scf. Exhaust gases can be used directly to heat dry kilns, etc.

Fluid Bed Combustors. Fluidized beds for combustion of wood residues are recent developments and good emission data are scarce. Most systems require gas cleaning equipment and emissions therefore depend on collector efficiency. One commercial-scale installation using cyclone collectors reports emissions to the atmosphere at about 0.074 gr/scf.

Gasification. Results of emission tests on discharges to the atmosphere from a 1/10-scale pilot plant operating on hog fuel (6 units/8-h day) show very low concentrations of particulate matter. Emissions in the flare gas from the scrubber incinerator are reported at 0.10 gr/scf or less. Emissions from the process burner producing hot gases for direct use are reported at 0.004 gr/scf. No secondary gas cleaners are used.

Fluidized Bed Charcoal Reactor. No emission data are available at present. Since most inorganic particulate matter will remain with the charcoal, particulate emissions are expected to be low. Emissions

will depend on the effectiveness of dry cyclones in removing charcoal entrained with by-product combustible gas.

10.3 Product Development

Marketable products can be derived from some wood residues. Wood chips (and some sawdust) are being sold to pulp mills. Consumption of charcoal from wood residues is increasing. Surplus wood residues are available for the production of charcoal and activated carbon in quantities that could supply a large export market. A process for continuous charcoal production is in operation. Technology exists to make fire logs directly from wet wood but an aggressive merchandizing effort is needed.

10.4 Regional Energy Recovery

Central regional energy recovery plants using wood residue can be designed to meet requisite environmental standards. They could produce electricity by established technology, SNG by known technology (in an active state of development) or fuel-grade methanol (from methane produced by gasification reactions) by known technology.

10.5 Required Research

There are a considerable number of aspects of wood residue disposal that require more detailed study:

- (a) Control of the modified conical incinerator particularly when handling wet wood residues;
- (b) Design and operation of pit incinerators;
- (c) Development of techniques for removing salt from combustion gas of hog fuel from saltwater-floated logs;
- (d) Development of new direct uses of clean combustion gas available from new wood-burning systems;
- (e) Study of technical and economic feasibility of central regional energy recovery plants using wood residues;
- (f) Production of high- and low-heat-value fuel by gasification of wood;
- (g) Study of the technical and economic feasibility of fuel-grade methanol production as a means of recovering, storing, transporting and using available energy in wood and wood residues.

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APPENDIX

TERMINOLOGY AND CONVERSION UNITS

WOOD RESIDUES

Common name	Size range	Moisture range (%) (wet basis)	Ash and dirt content (%)
Sanderdust	100 micron - 1/32 in.	2 - 8	0.1 - 0.5
Shavings	1/32 - 1/2 in.	10 - 20	0.1 - 1.0
Sawdust	1/32 - 3/8 in.	25 - 40	0.5 - 2.0
Bark (Hogged)	1/32 - 4 in.	25 - 75	1.0 - 2.0
Yard cleanup	up to 4 in.	40 - 60	5.0 - 50
Forest residuals	needles to stumps	30 - 60	3.0 - 20
Fly carbon	small	zero	1.0 - 10 (screened)

CONVERSION UNITS

1 Cunit = 100 ft³ solid wood

1 Cunit = 600 fbm

Wood residue to log cut = 0.55 units/cunit (approx.) (bark, sawdust and shavings)

1 unit wood residue
(hog fuel) = 200 ft³ gravity packed

Weight of dry wood per unit varies with species

Douglas Fir sawdust	1900 lb dry wood/unit
Hemlock sawdust	1700 lb
Douglas Fir bark	2600 lb
Hemlock bark	2200 lb
Typical mixture	2000 lb (approx.)

Wood residue generation (calculated)
(bark + sawdust + shavings)

Wood residue (Corder (12))	Sawdust	-	13% of log (vol)
	Bark	-	12%
	Shavings	-	10%

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